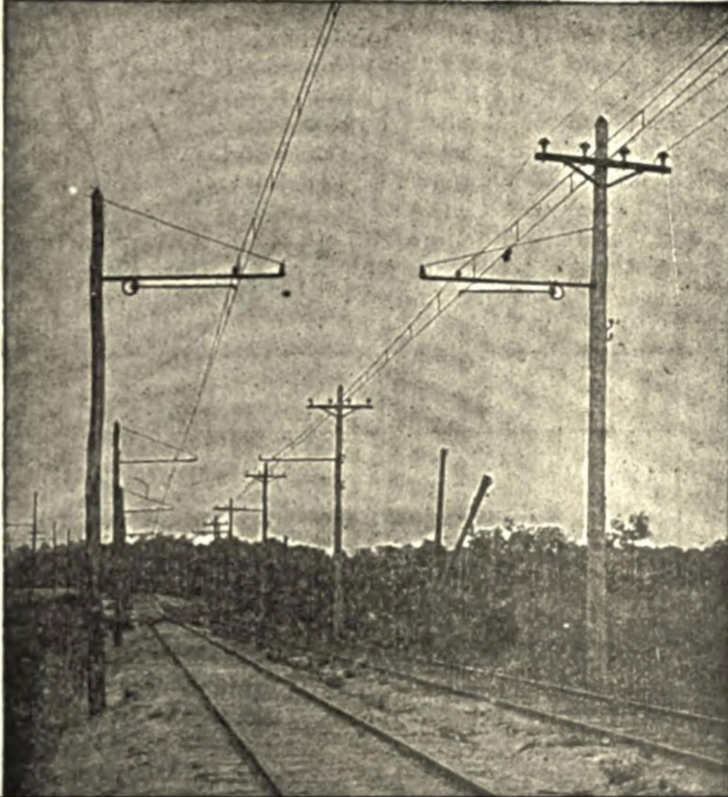

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ELECTRICAL GUIDE
NUMBER SEVEN

QUESTIONS ANSWERS & ILLUSTRATIONS

A PROGRESSIVE COURSE OF STUDY
FOR ENGINEERS, ELECTRICIANS, STUDENTS
AND THOSE DESIRING TO ACQUIRE A
WORKING KNOWLEDGE OF

ELECTRICITY AND ITS APPLICATIONS

A PRACTICAL TREATISE

by

HAWKINS AND STAFF

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CHAPTER LV

ALTERNATING CURRENT SYSTEMS

The facility with which alternating current can be transformed from one voltage to another, thus permitting high pressure transmission of electric energy to long distances through small wires, and low pressure distribution for the operation of lighting systems and motors, gives a far greater variety of systems of transmission and distribution than is possible with direct current.

Furthermore, when the fact that two phase current can be readily transformed into three phase current, and these converted into direct current, and vice versa, by means of rotary converters and rectifiers, is added to the advantages derived by the use of high tension systems, it is apparent that the opportunity for elaboration becomes almost unlimited. These conditions have naturally tended toward the development of a great variety of systems, employing more or less complicated circuits and apparatus, and although alternating current practice is still much less definite than direct current work, certain polyphase systems are now being generally accepted as representing the highest standards of power generation, transmission and distribution.

A classification of the various alternating current systems, to be comprehensive, should be made according to several points of view, as follows:

1. With respect to the arrangement of the circuit, as
   - *a.* Series;
   - *b.* Parallel;
   - *c.* Series parallel;
   - *d.* Parallel series.

2. With respect to transformation, as

   Transformer;

3. With respect to the mode of transmitting the energy, as
   - *a.* Constant pressure;
   - *b.* Constant current.

4. With respect to the kind of current, as
   - *a.* Single phase
     - two wire;
     - three wire;
   - *b.* Monocyclic
   - *c.* Two phase
     - four wire;
     - three wire;
     - five wire;
   - *d.* Three phase
     - six wire;
     - three wire;
     - four wire;
     - star connection;
     - delta connection;
     - star delta cnnnection;
     - delta star connection;
   - *e.* Multi-phase
     - of more than three phases;

5. With respect to transmission and distribution, as
   - *a.* Frequency changing;
   - *b.* Phase changing;
   - *c.* Converter;
   - *d.* Rectifier.

In order to comprehend the relative advantages of the various alternating current systems, it is first necessary to understand iple of *vector summation.*

Vector Summation.—This is a simple geometrical process for ascertaining the pressure at the free terminals of alternating current circuits. The following laws should be carefully noted:

1. *If two alternating pressures which agree in phase are connected together in series, the voltage at the free terminals of the circuit will be equal to their arithmetical sum, as in the case of direct currents.*

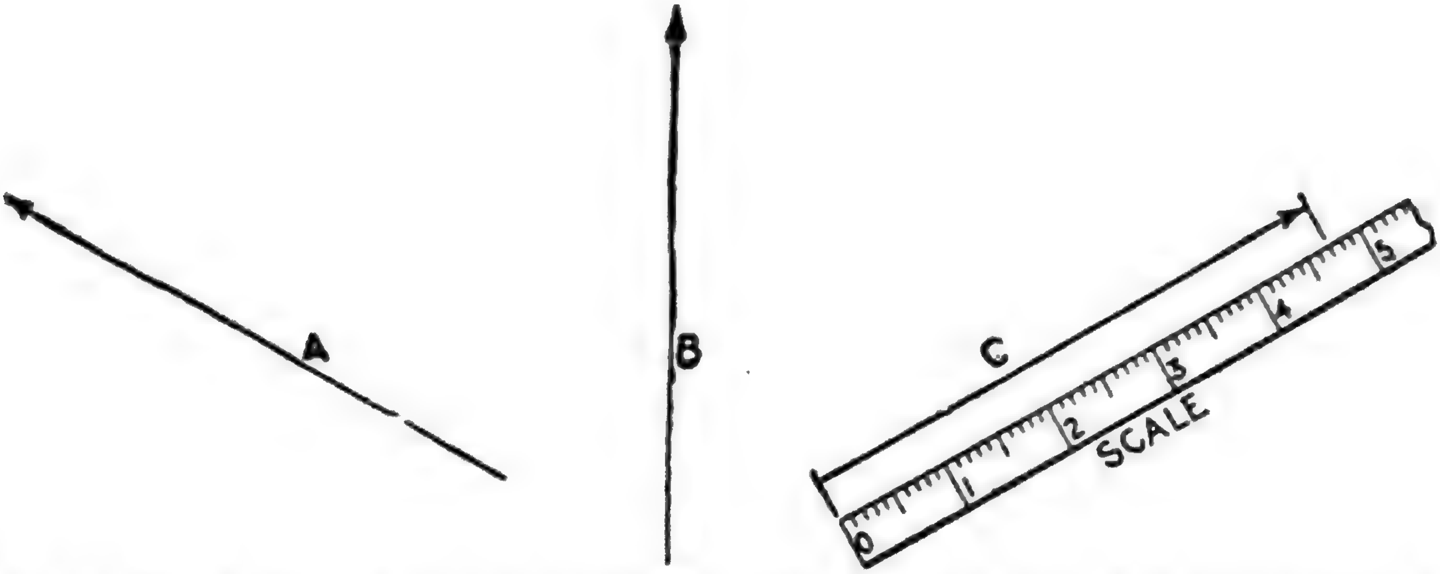


FIG. 2,123.—*Vectors.* **A vector is defined as:** *a line, conceived to have both a fixed length and a fixed direction in space, but no fixed position.* Thus A and B are lines, each having a fixed length, but no fixed direction. **By adding an arrow head** the direction is fixed and the line becomes a vector, as for example vector C. The fixed length is usually taken to represent a definite force, thus the fixed length of vector C is 4.7 which may be used to represent 4.7 lbs., 4.7 tons, etc., as may be arbitrarily assumed.

When there is phase difference between the two alternating pressures, connected in series, the following relation holds:

2. *The value of the terminal voltage will differ from their arithmetical sum, depending on the amount of their phase difference.*

When there is phase difference, the value of the resultant is conveniently obtained as explained below.

Ques. How are vector diagrams constructed for obtaining resultant electric pressure?

Ans. On the principle of the *parallelogram of forces.*

Ques. What is understood by the parallelogram of forces?

Ans. It is a graphical method of finding the resultant of two forces, according to the following law: *If two forces acting on a point be represented in direction and intensity by adjacent sides of a parallelogram, their resultant will be represented by the diagonal of the parallelogram which passes through the point.*

Thus in fig. 2,124, let OA and OB represent the intensity and direction of two forces acting at the point O. Draw AC and BC, respectively parallel to OB and OA, completing the parallelogram, then will OC, the diagonal from the point at which the forces act, represent the intensity and direction of the resultant, that is, of a force equivalent to the combined action of the forces OA and OB, these forces being called the *components* of the force OC.

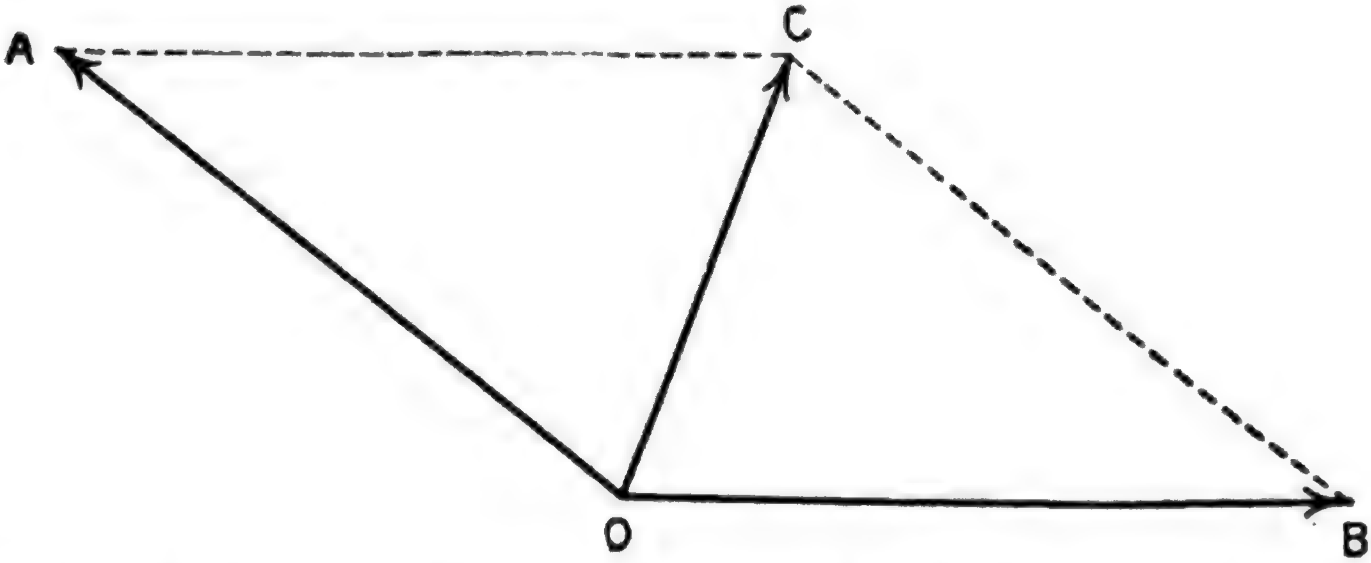


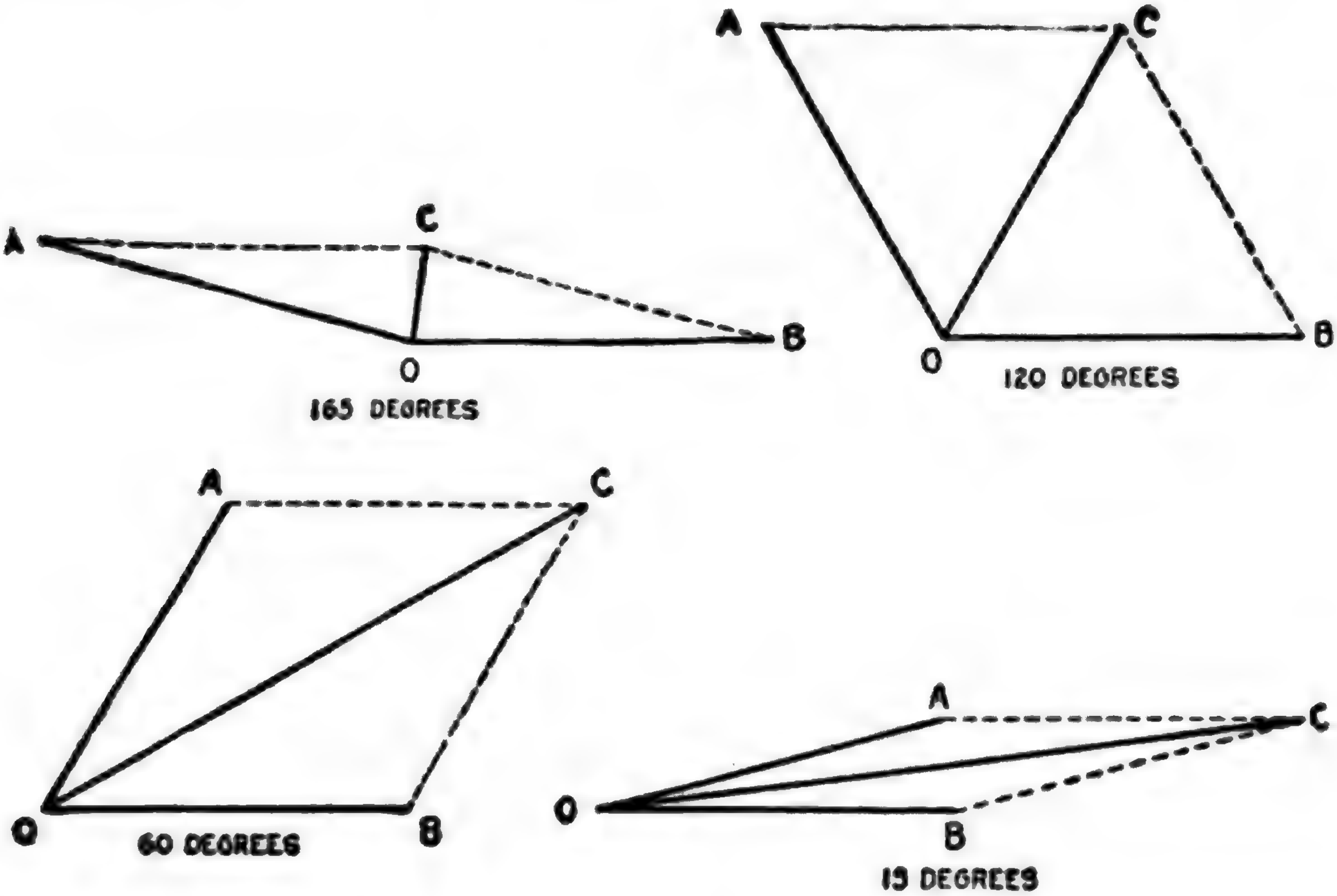
FIG. 2,124.—Parallelogram of forces. OC is the resultant of the two forces OA and OB. The length and direction of the lines represent the intensity and direction of the respective forces, the construction being explained in the accompanying text.

Ques. Upon what does the magnitude of the resultant of two forces depend?

Ans. Upon the difference in directions in which they act, as shown in figs 2,125 to 2,128.

Ques. Is the parallelogram of forces applied when the difference in direction or "phase difference" of two forces is 90 degrees?

Ans. It is sometimes more conveniently done by calculation according to the law of the right angle triangle.



FIGS. 2,125 to 2,128.—Parallelograms of forces showing increase in magnitude of the resultant of two forces, as their difference of direction, or electrically speaking, their *phase difference* is diminished. The diagrams show the growth of the resultant of the two equal forces OA and OB as the phase difference is reduced from 165° successively to 120, 60, and 15 degrees.

According to this principle, if two alternating pressures have a phase difference of 90 degrees they may be represented in magnitude and direction by the two sides of a right angle triangle as OA and OB in fig. 2,129; then will the hypotenuse AB represent the magnitude and direction of the resultant pressure. That is to say, the resultant pressure

$$AB = \sqrt{\overline{OA}^2 + \overline{OB}^2} \quad . \quad . \quad . \quad . \quad . \qquad (1)$$

EXAMPLE.—A two phase alternator is wound for 300 volts on one phase and 200 volts on the other phase, the phase difference being 90°. If one end of each winding were joined so as to form a single winding around the armature, what would be the resultant pressure?

By calculation, substituting the given values in equation (1),

$$\text{Resultant pressure} = \sqrt{300^2+200^2} = \sqrt{130{,}000} = 360.6 \text{ volts.}$$

This is easily done graphically as in fig. 2,129 by taking a scale, say, 1″ = 100 volts and laying off OA = 3″ = 300 volts, and at right angles OB = 2″ = 200 volts, then by measurement AB = 3.606″ = 360.6 volts.

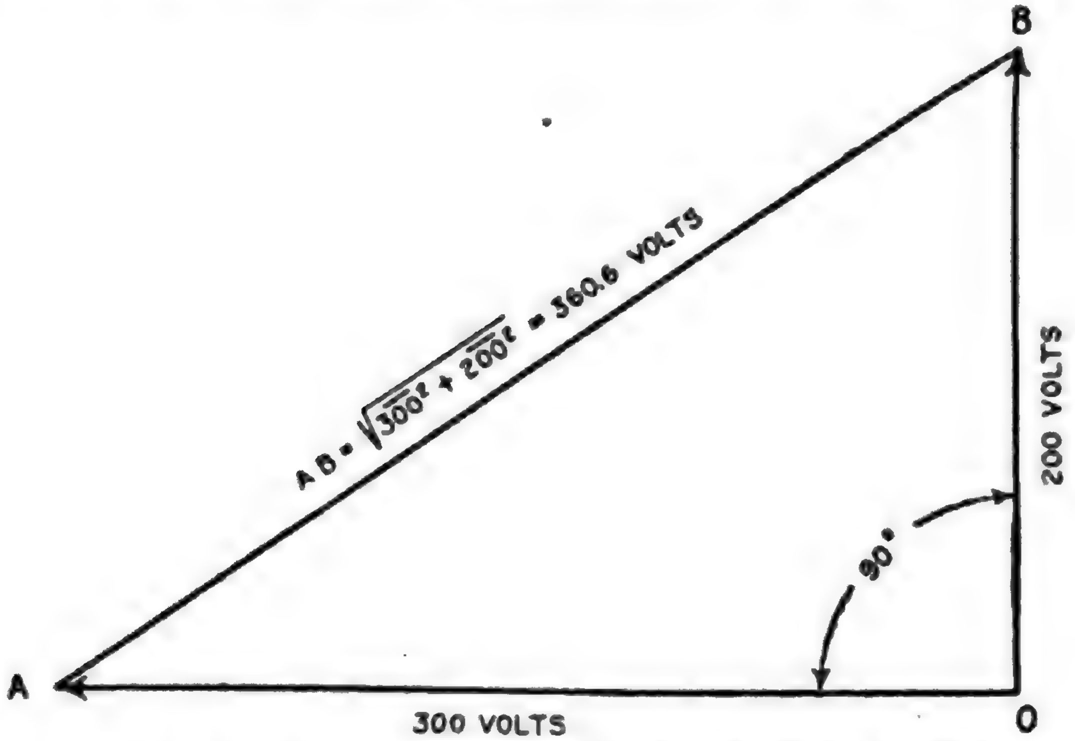


FIG. 2,129.—Method of obtaining the resultant of two component pressures acting at right angles by solution of right angle triangle. The equation of the right angle triangle is explained at length in Guide No. 5, page 1,070.

Ques. When the two pressures are equal and the phase difference is 90°, is it necessary to use equation (1) to obtain the resultant?

Ans. No. The resultant is obtained by simply multiplying one of the pressures by 1.41.

This is evident from fig. 2,130. Here the two pressures OA and OB are equal as indicated by the dotted arc. Since they act at right angles, OB is drawn at 90° to OA. According to the equation of the right angle triangle, the resultant AB = $\sqrt{1^2+1^2} = \sqrt{2} = 1.4142$ which ordinarily is taken as 1.41.

This value will always represent the ratio between the magnitude of the resultant and the two component forces, when the latter are equal, and have a phase difference of 90 *degrees.*

Forms of Circuit.—Alternating current systems of distribution may be classed, with respect to the kind of circuit used, in a manner similar to direct current systems, that is, they may be called series, parallel, series parallel, or parallel series systems, as shown in figs. 2,131 to 2,134.

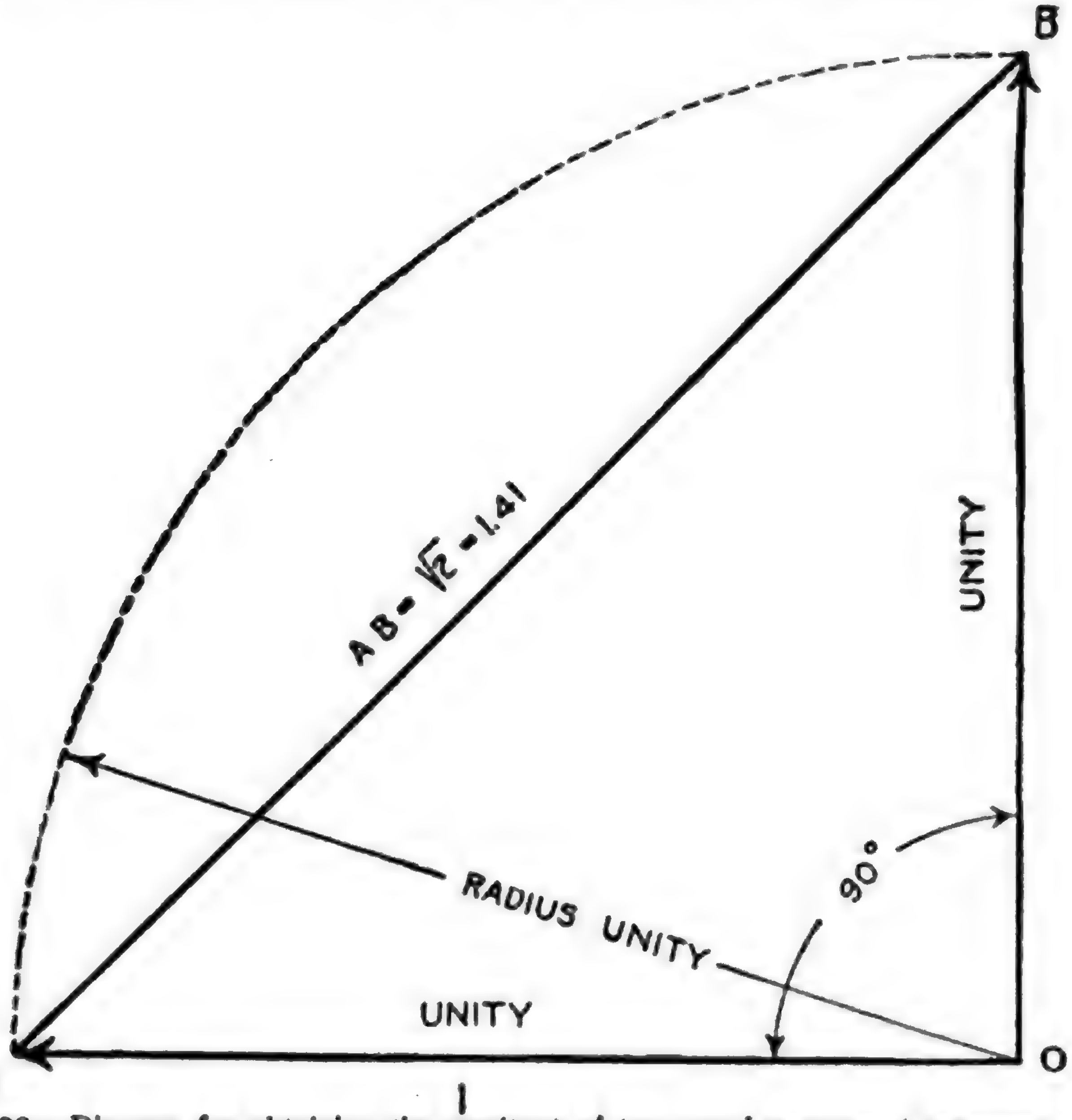
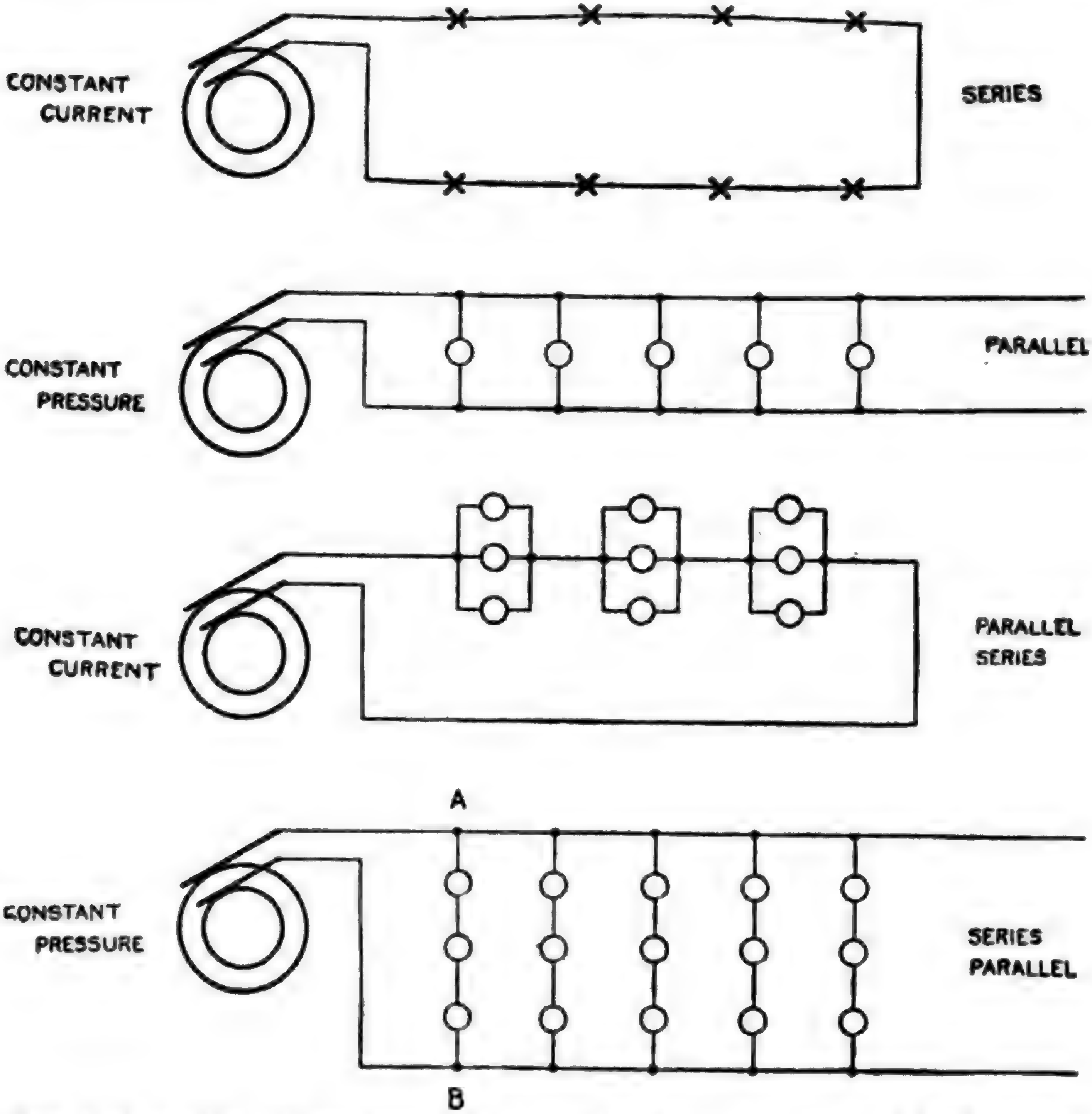


Fig. 2,130.—Diagram for obtaining the resultant of two equal component pressures acting at right angles.

Series Circuits.— These are used in arc lighting, and series incandescent lighting, a constant current being maintained; also for constant current motors and generators supplying secondary circuits.

Several forms of constant current alternator, analogous to the Thompson-Houston and Brush series arc dynamos, have


CONSTANT CURRENT
SERIES
CONSTANT PRESSURE
PARALLEL
CONSTANT CURRENT
PARALLEL SERIES
A
CONSTANT PRESSURE
SERIES PARALLEL
B

FIGS. 2,131 to 2,134.—Various forms of circuit. These well known forms of circuit are used in both alternating and direct current systems. The simple series circuit, fig. 2,131, is suitable for constant current arc lighting. Fig. 2,132, shows the parallel constant pressure circuit; this form of circuit is largely used but is seldom connected direct to the alternator terminals, but to a step down transformer, on account of the low pressure generally required. Fig. 2,133 illustrates a parallel series circuit, and 2,134, a series parallel circuit.

been introduced. In the design of such alternators self-induction and armature reaction are purposely exaggerated; so that the current does not increase very much, even when the machine is short circuited. With this provision, no regulating device is required.

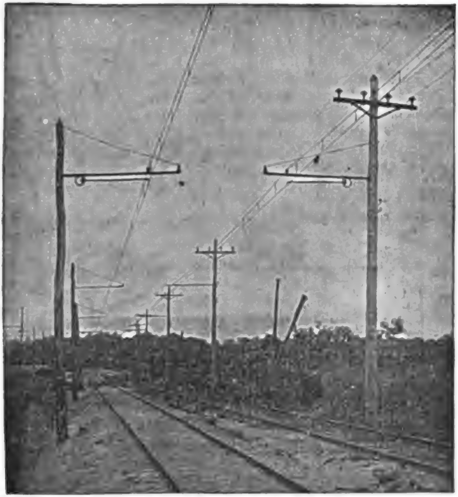


FIG. 2.135.—Typical American overhead 6,600 volt single phase interurban trolley line, Baltimore and Annapolis short line, Annapolis, Md.

An objectionable feature is that the voltage of a constant current alternator will rise very high if the circuit be opened, because it is then relieved of inductance drop and armature reaction.

To guard against a dangerous rise of voltage, a film cut out or equivalent device is connected to the terminal of each machine so that it will short circuit the latter if the voltage rise too high.

Ques. What advantage have constant current alternators over constant current dynamos?

Ans. The high pressure current is delivered to the external circuit without a commutator, hence there is no sparking difficulty.

The above relates to the revolving field type of alternator. There are, however, alternators in which the armature revolves, the current being delivered to the external circuit through collector rings and brushes. This type of alternator, it should be noted, is for moderate pressures, and moreover there is no interruption to the flow of the current such as would be occasioned by a tangential brush on a dynamo in passing from one commutator segment to the next.

In the revolving field machine, though the armature current be of very high pressure, the field current which passes through the brushes and slip rings is of low pressure and accordingly presents no transmission difficulties.

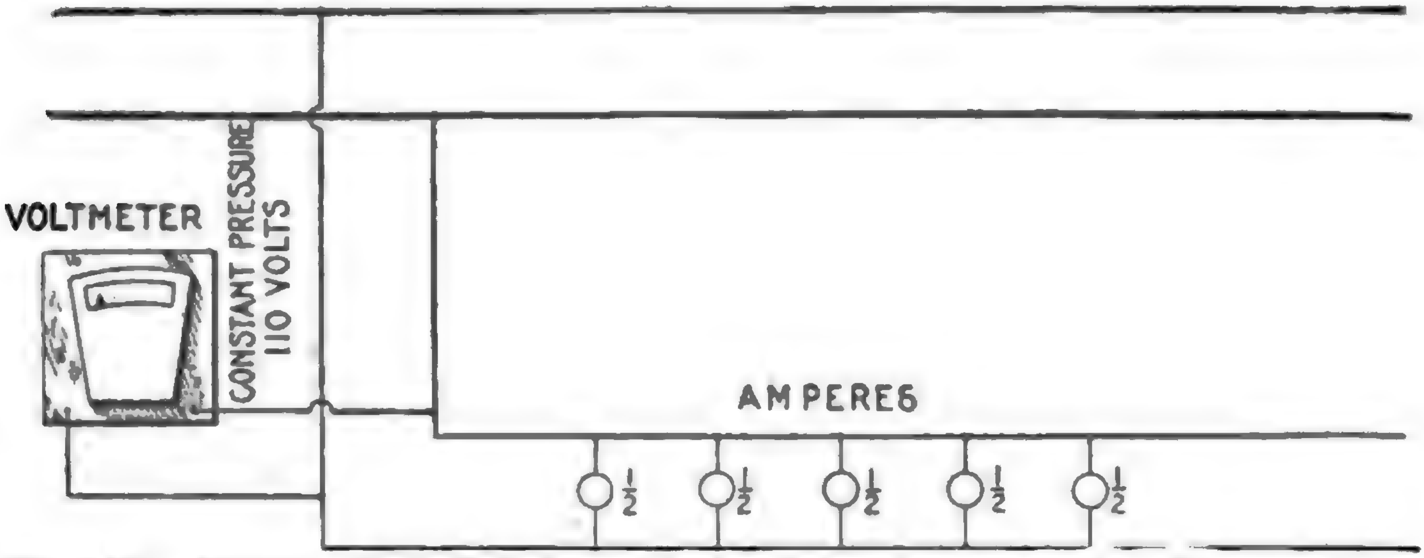


FIG. 2,136.—**Diagram of parallel circuit.** *It is a constant pressure circuit* and is very widely used for lighting and power. If each lamp take say ½ ampere, the current flowing in the circuit will vary with the number of lamp in operation; in the above circuit with all lamps on, the current is ½ × 5 = 2½ amperes.

Ques. State a disadvantage.

Ans. Some source of direct current for field excitation is required.

Ques. In a constant current series system, upon what does the voltage at the alternator depend?

Ans. The number of devices connected in the circuit, the volts required for each, and the line drop.

Parallel Circuits.—These are used for constant pressure operation. Such arrangement provides a separate circuit for each unit making them independent so that they may vary in size and each one can be started or stopped without interfering with the others. Parallel circuits are largely used for incandescent lighting, and since low pressure current is commonly used on such circuits they are usually connected to step down transformers, instead of direct to the alternators.

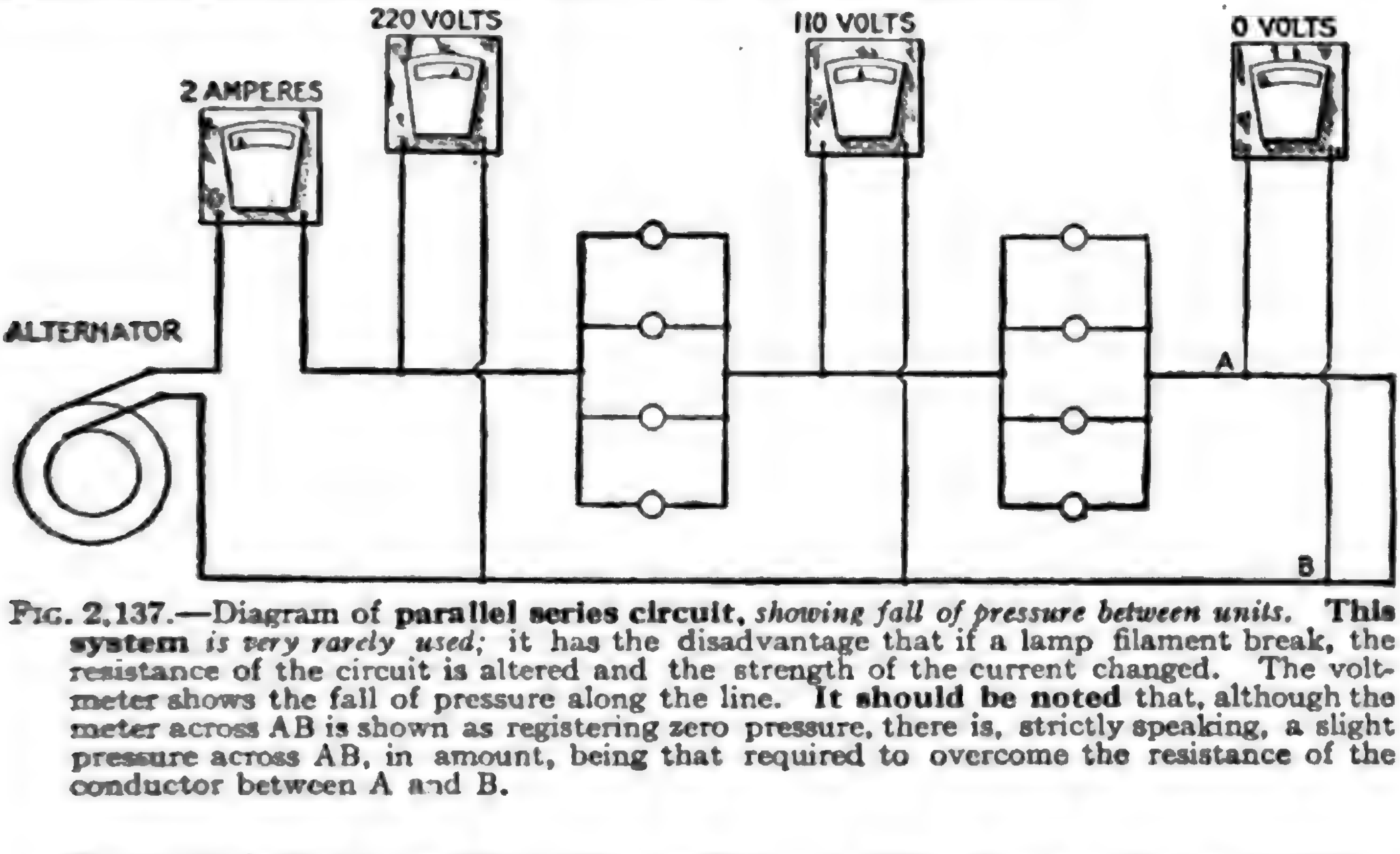


FIG. 2,137.—Diagram of **parallel series circuit,** *showing fall of pressure between units.* **This system** *is very rarely used;* it has the disadvantage that if a lamp filament break, the resistance of the circuit is altered and the strength of the current changed. The voltmeter shows the fall of pressure along the line. **It should be noted** that, although the meter across AB is shown as registering zero pressure, there is, strictly speaking, a slight pressure across AB, in amount, being that required to overcome the resistance of the conductor between A and B.

Parallel Series Circuits.—Fig. 2,137 shows the arrangement of a parallel series circuit and the pressure conditions in same. Such a circuit consists of groups of two or more lamps or other devices connected in parallel and these groups connected in series.

Such a circuit, when used for lighting, obviously has the disadvantage that if a lamp filament break, the resistance of the group is increased, thus reducing the current and decreasing the brilliancy of the lamps. This arrangement accordingly does not admit of turning off any of the lights.

Series Parallel Circuits.—The arrangement of circuits of this kind is shown in fig. 2,134: they are used to economize in copper since by joining groups of low pressure lamps in series they may be supplied by current at correspondingly higher pressure.

Thus, if in fig. 2,134, 110 volt, ½ ampere lamps be used, the pressure on the mains, that is, between any two points as A and B would be 110×3=330 volts. Each group would require ½ ampere and the five groups ½×5=2½ amperes.

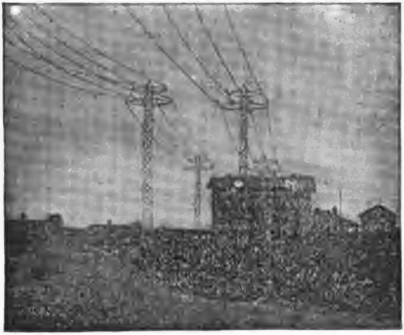


FIG. 2,138.—44,000 volt lines entering the Gastonia sub-station of the Southern Power Co The poles used are of the twin circuit two arm type, built of structural steel, their height varying from 45 to 80 feet, the latter weighing 9,000 pounds each. These poles have their bases weighted with concrete.

Transformer Systems.—Nearly all alternating current systems are transformer systems, since the chief feature of alternating current is the ease with which it may be transformed from one pressure to another. Accordingly, considerable economy in copper may be effected by transmitting the current at high pressure, especially if the distance be great, and, by means of step down transformers; reducing the voltage at points where the current is used or distributed.

Ordinarily and for lines of moderate length, current is sent ut direct from the alternator to the line and transformed by tep down transformers at the points of application.

With respect to the step down transformers, there are two rrangements:

1. Individual transformers;
2. One transformer for several customers.

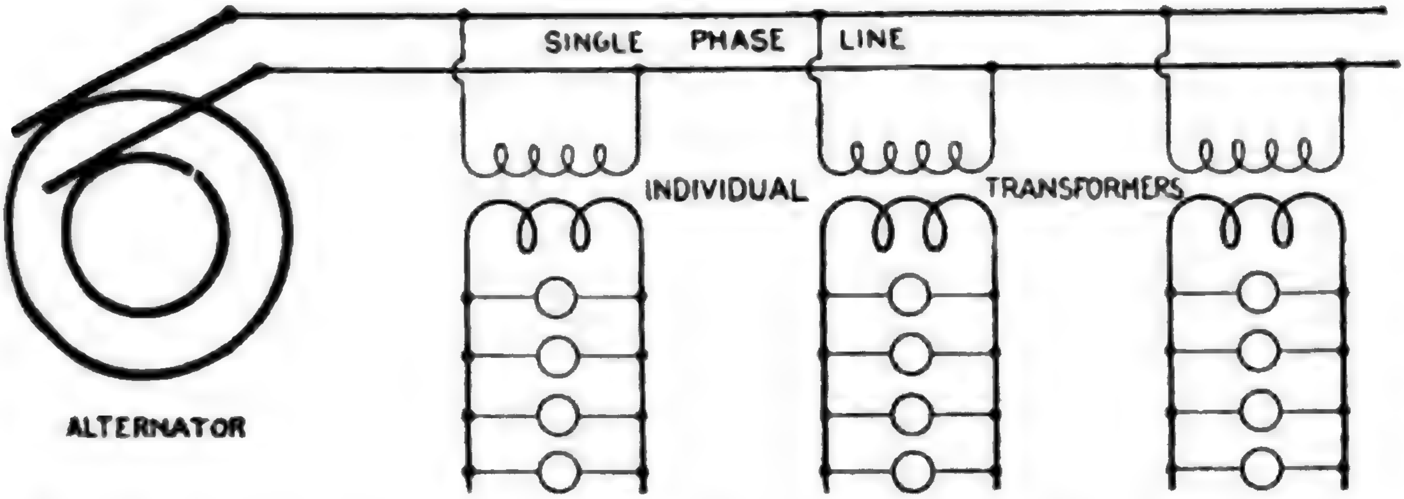


Fig. 2,139.—Diagram of transformer system with individual transformers. The efficiency is low, but such method of distribution is necessary in sparsely settled or rural districts.

Individual transformers, that is, a separate transformer for each customer is necessary in rural districts where the intervening distances are great as shown in fig. 2,139.

Ques. What are the objections to this method of distribution?

Ans. It requires the use of small transformers which are necessarily less efficient and more expensive per kilowatt than large transformers. The transformer must be built to carry, within its overload capacity, all the lamps installed by the customer. since all may be used occasionally.

Usually, however, only a small part of the lamps are in use, and those only for a small part of the day, so that the average load on the transformer is a very small part of its capacity. Since the core loss continues whether the transformer be loaded or not, but is not paid for by the customer, the economy of the arrangement is very low.

In the second case, where one large transformer may be placed at a distribution center, to supply several customers, as in fig. 2,140, the efficiency of the system is improved.

Ques. Why is this arrangement more efficient than when individual transformers are used?

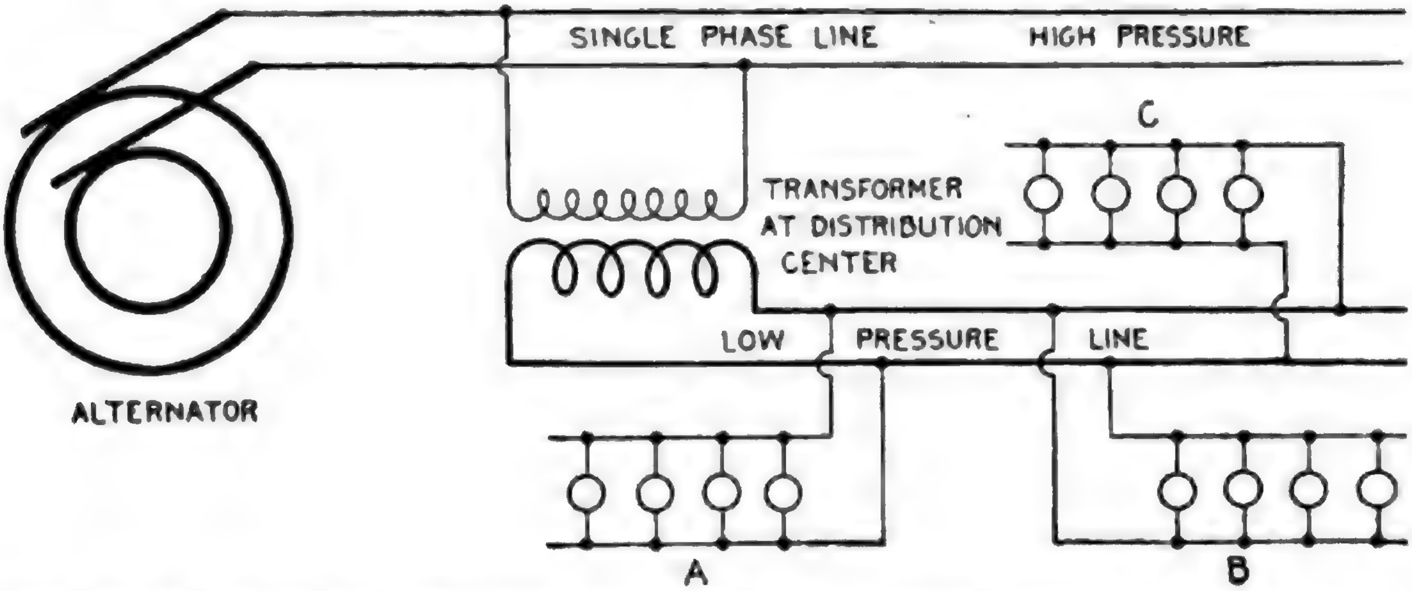


FIG. 2,140.—Diagram of transformer system with one transformer located at a distribution center and supplying several customers as A, B, and C. Such arrangement is considerably more efficient than that shown in fig. 2,139, as explained in the accompanying text.

Ans. Less transformer capacity is required than with individual transformers.

Ques. Why is this?

Ans. With several customers supplied from one transformer it is extremely improbable that all the customers will burn all their lamps at the same time. It is therefore unnecessary to install a transformer capable of operating the full load, as is necessary with individual transformers.

Ques. Does the difference in transformer capacity represent all the saving?

Ans. No; one large transformer is more efficient than a number of small transformers.

Ques. Why?

Ans. The core loss is less.

For instance, if four customers having 20 lamps each were supplied from a single transformer, the average load would be about 8 lamps, and at most not over 10 or 15 lamps, and a transformer carrying 30 to 35 lamps at over load would probably be sufficient. A 1,500 watt transformer would therefore be larger than necessary. At 3 per cent. core loss, this gives a constant loss of 45 watts, while the average load of 8 lamps for 3 hours per day gives a useful output of 60 watts, or an all year efficiency of nearly 60 per cent., while a 1,000 watt transformer would give an all year efficiency of 67 per cent.

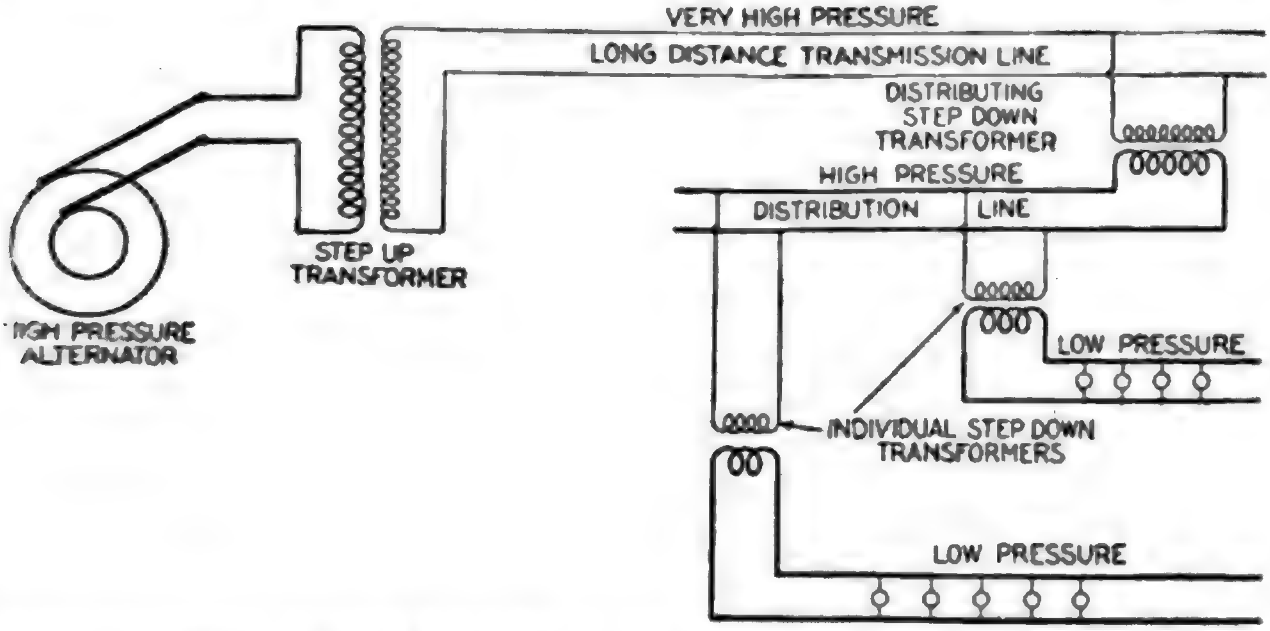

VERY HIGH PRESSURE
LONG DISTANCE TRANSMISSION LINE
DISTRIBUTING STEP DOWN TRANSFORMER
HIGH PRESSURE
DISTRIBUTION
LINE
STEP UP TRANSFORMER
HIGH PRESSURE ALTERNATOR
LOW PRESSURE
INDIVIDUAL STEP DOWN TRANSFORMERS
LOW PRESSURE

FIG. 2,141.—Diagram illustrating the use of *step up* and *step down* transformers on long distance transmission lines. The saving in copper is considerable by employing extra high voltages on lines of moderate or great length as indicated by the relative sizes of wire.

For long distance transmission lines, the voltage at the alternator is increased by passing the current through a *step up* transformer, thus transmitting it at very high pressure, and reducing the voltage at the points of distribution by step down transformers as in fig. 2,141.

Ques. In practice, would such a system as shown in fig. 2,141 be used?

Ans. If the greatest economy in copper were aimed at, a three phase system would be used.

The purpose of fig. 2,141 is to show the importance of the transformer in giving a flexibility of voltage, by which the cost of the line is reduced to a minimum.

Ques. Does the saving indicated in fig. 2,141 represent a net gain?

Ans. No. The reduction in cost of the transmission is partly offset by the cost of the transformers as well as by transformer losses and the higher insulation requirements.

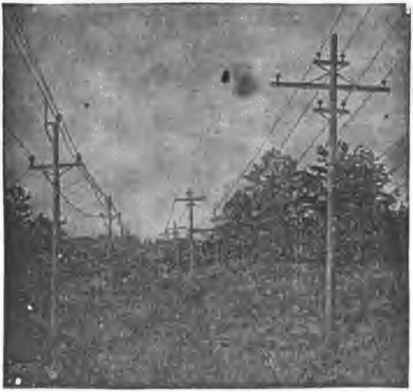


FIG. 2,142.—Single and twin circuit poles (Southern Power Co.). The twin circuit pole at the right is used for 11,000 volt circuits, while the single circuit poles at the left carry 44,000 volt conductors, being used on another division for 100,000 volt line.

Every case of electric transmission presents its own problem, and needs thorough engineering study to intelligently choose the system best adapted for the particular case.

Single Phase Systems.—There are various arrangements for transmission and distribution classed as single phase systems. Thus, single phase current may be conveyed to the various receiving units by the well known circuit arrangements known as series, parallel, series parallel, parallel series, connections previously described and illustrated in figs. 2,131 to 2,134.

Again single phase current may be transmitted by two wires and distributed by three wires. This is done in several ways, the simplest being shown in fig. 2,143.

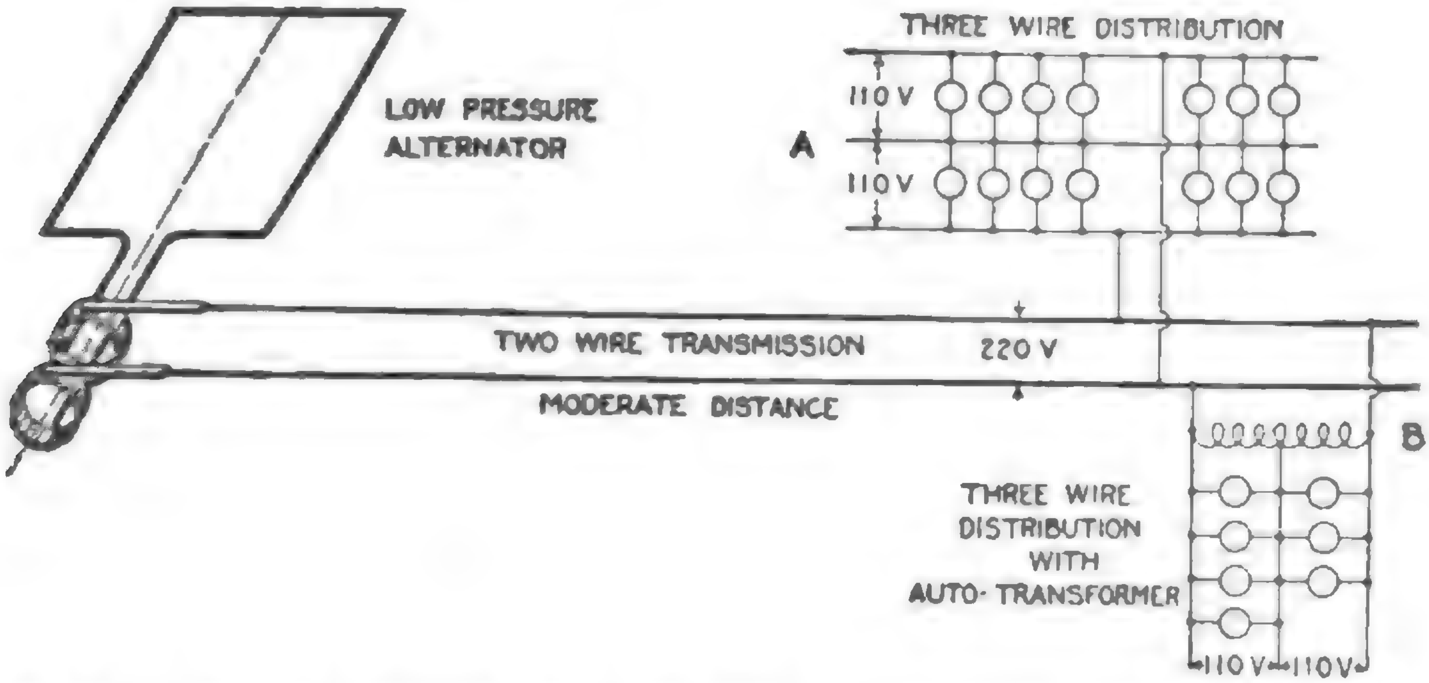

THREE WIRE DISTRIBUTION
110 V
110 V
LOW PRESSURE ALTERNATOR
A
TWO WIRE TRANSMISSION
220 V
MODERATE DISTANCE
B
THREE WIRE DISTRIBUTION WITH AUTO-TRANSFORMER
110 V
110 V

FIG. 2,143.—Diagram illustrating single phase two wire transmission and three wire distribution. The simplified three wire arrangement at A, is not permissible except in cases of very little *unbalancing*. Where the difference between loads on each side of the neutral may be great some form of balancing as an auto-transformer or equivalent should be used, as at B.

Ques. Under what conditions is the arrangement shown in fig. 2,143 desirable?

Ans. This method of treating the neutral wire is only permissible where there is very little unbalancing, that is, where the load is kept practically the same on both sides of the neutral.

Ques. What advantage is obtained by three wire distribution?

Ans. The pressure at the alternator can be doubled, which means, for a given number of lamps, that the current is reduced

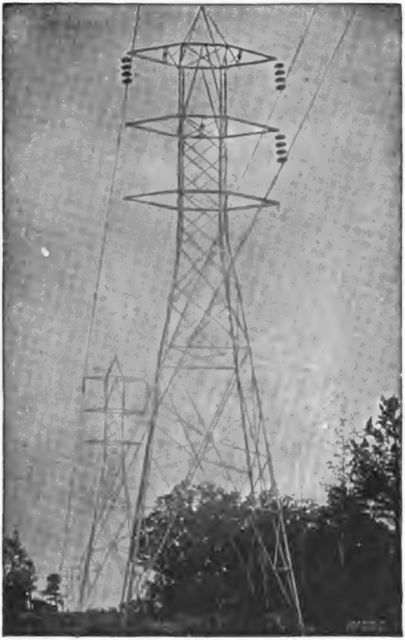


FIG. 2,144.—100,000 volt "Milliken" towers with one circuit strung (Southern Power Co.). These towers are mounted on metal stubs sunk 6 feet in the ground. Where the angle of the line is over 15 degrees, however, these stubs are weighted with rock and concrete, and where an angle of over 30 degrees occurs, two and sometimes three towers are used for making the turn. The weight of the standard "Milliken" tower is 3,080 lbs., and its height from the ground to peak is 51 feet. The towers are spaced to average eight to a mile and a strain tower weighing 4,250 lbs. is used every mile. For particularly long spans a special heavy tower weighing 6,000 lbs. is used. The circuits are transposed every 30 miles. Multiple disc insulators are used, four discs being used to suspend each conductor from standard towers and ten discs to each conductor on strain towers. The standard span is 600 feet, sag 11 ft at 50° Fahr.

to half, the permissible drop may be doubled, the resistance of the wires quadrupled, and their cost reduced nearly 75 per cent.

Ques. What modification of circuit A (fig. 2,143), should be made to allow for unbalancing in the three wire circuit?

Ans. An autotransformer or "balance coil" as it is sometimes called should be used as at B.

This is a very desirable method of balancing when the ratio of transformation is not too large.

Ques. For what service would the system shown in fig. 2,143 be suitable?

Ans. For short distance transmission, as for instance, in the case of an isolated plant because of the low pressure at which the current is generated.

The standard voltages of low pressure alternators are 400, 480, and 600 volts.

Ques. In practice are single phase alternators used as indicated in fig. 2,143?

Ans. Alternators are wound for one, two or three phases. Three phase machines are more commonly supplied and in many cases it will pay to install them in preference to single phase, even if they be operated single phase temporarily.

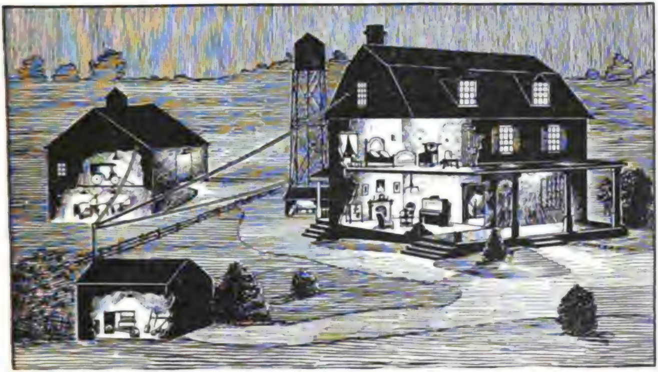


FIG. 2,145.—View of a typical isolated plant. The illustration represents an electric lighting plant on a farm showing the lighting of the dwelling, barn, tool house and pump house. The installation consists of a low voltage dynamo with gas engine drive and storage battery together with the necessary auxiliary apparatus.

For a given output, three phase machines are smaller than single phase and the single phase load can usually be approximately balanced between the three phases. Moreover, if a three phase machine be installed, polyphase current will be available in case it may be necessary to operate polyphase motors at some future time.

Standard three phase alternators will carry about 70 per cent. of their rated kilowatt output when operated single phase, with the same temperature rise.

Ques. How are three phase alternators used for phase circuits?

Ans. The single phase circuit is connected to any two o three phase terminal leads.

Ques. What form of single phase system should be used where the transmission distance is considerable?

Ans. The current should be transmitted at high pressure, a step down transformer being placed at each distribution center to reduce the pressure to the proper voltage to suit the service requirements as shown in fig. 2,146.

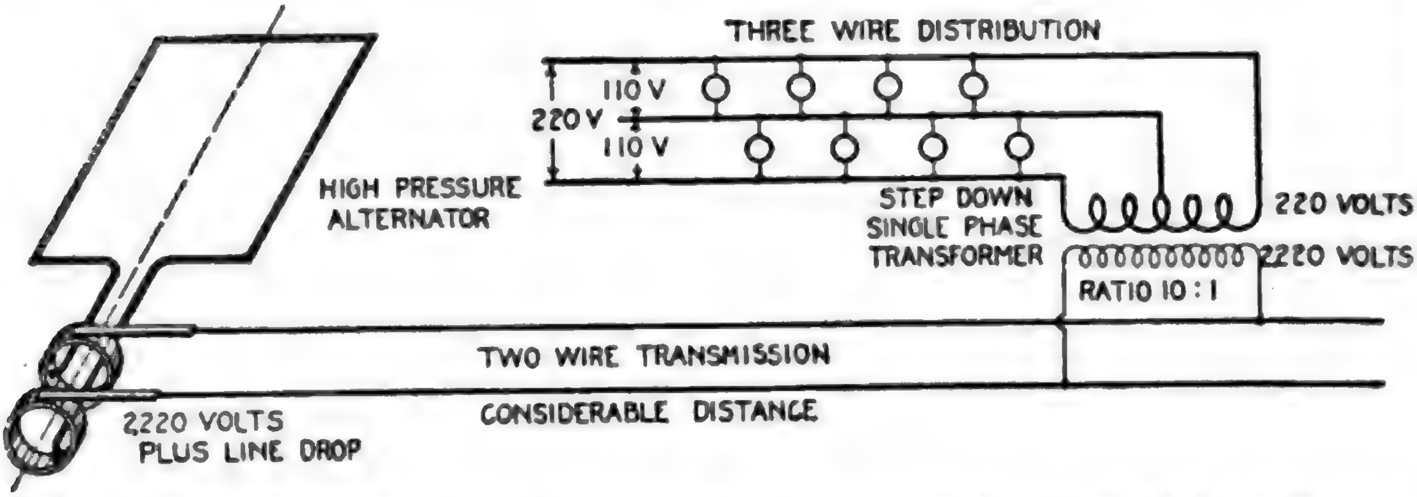

THREE WIRE DISTRIBUTION
110 V
220 V
110 V
HIGH PRESSURE ALTERNATOR
STEP DOWN SINGLE PHASE TRANSFORMER
220 VOLTS
2220 VOLTS
RATIO 10 : 1
TWO WIRE TRANSMISSION
CONSIDERABLE DISTANCE
2220 VOLTS PLUS LINE DROP

FIG. 2,146.—Diagram showing **arrangement of single phase system** for two wire transmission and three wire distribution, *where the transmission distance* **is considerable.** In order **to reduce the cost** of the transmission line, *the current must be transmitted at high pressure;* this necessitates the use of a step down transformer at the distributing center as shown in the illustration.

Thus, if 110 volt lamps be used on the three wire circuit, the pressure between the two outer wires would be 220 volts. A transformation ratio of say 10:1 would give 2,220 volts for the primary circuit. The current required for the primary with this ratio being only .1 that used in the secondary, a considerable saving is effected in the cost of the transmission line as must be evident.

With the high pressure alternator only one transformation of the current is needed, as shown at the distribution end.

In place of the high pressure alternator, a low pressure alternator could be used in connection with a step up transformer as shown in fig. 2,147, but there would be an extra loss due to the additional transformer, rendering the system less efficient than the one shown in fig. 2,146. Such an arrangement as shown in the fig. 2,147 might be justified

n the case of a station having a low pressure alternator already in use
d it should be desired to transmit a portion of the energy a consider-
le distance.

**es. How could the system shown in fig. 2,147 be
.de more efficient than that of fig. 2,146.**

Ans. By using a high pressure alternator in order to con-
iderably increase the transmission voltage.

Thus, a 2,200 volt alternator and 1:10 step up transformer would give a line pressure of 22,000 volts, which at the distribution end could be reduced, to 220 volts for the three wire circuit, using a 100:1 step down transformation.

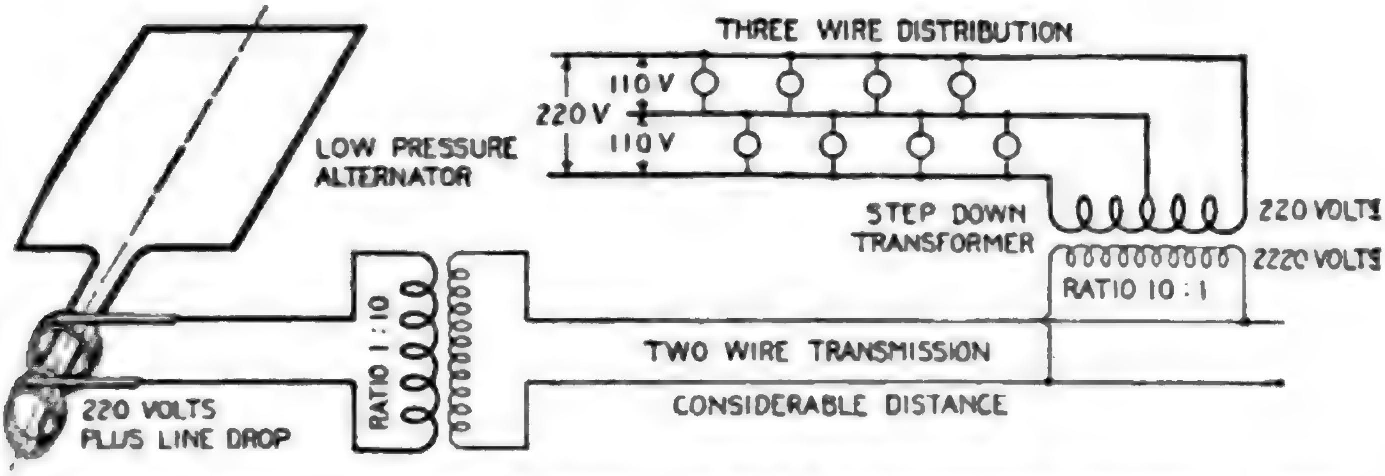

THREE WIRE DISTRIBUTION
110 V
220 V
110 V
LOW PRESSURE ALTERNATOR
STEP DOWN TRANSFORMER
220 VOLTS
2220 VOLTS
RATIO 10 : 1
RATIO 1 : 10
TWO WIRE TRANSMISSION
CONSIDERABLE DISTANCE
220 VOLTS PLUS LINE DROP

FIG. 2,147.—Diagram illustrating how electricity can be economically transmitted a considerable distance with low pressure alternator already in use.

Ques. Would this be the best arrangement?

Ans. No.

Ques. What system would be used in practice for maximum economy?

Ans. Three phase four wire.

Ques. What are the objections to single phase generation and transmission?

Ans. It does not permit of the use of synchronous converters, self-starting synchronous motors, or induction motor starting under load. It is poorly adapted to general power

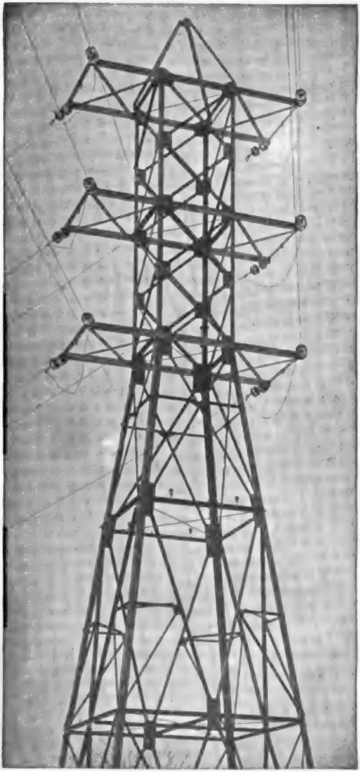


FIG. 2,148.—Angle tower showing General Electric strain insulators. The tower being subject to great tortional strains is erected on a massive concrete foundation. The construction is similar to the standard tower but of heavier material, and having the same vertical dimensions but with bases 20 ft. square.

distribution, hence it is open to grave objections of a commercial nature where there exists any possibility of selling power or in any way utilizing it for general converter and motor work.

Ques. For what service is it desirable?

Ans. For alternating current railway operation.

There are advantages of simplicity in the entire generating, primary, and secondary distribution systems for single phase roads. These advantages are so great that they justify considerable expense, looked at from the railway point of view only, the single phase system throughout may be considered as offering the most advantage.

Ques. What are the objectionable features of single phase alternators?

Ans. This type of alternator has an unbalanced armature reaction which is the cause of considerable flux variation in the field pole tips and in fact throughout the field structure.

In order to minimize eddy currents, such alternators must accordingly be built with thinner laminations and frequently poorer mechanical construction, resulting in increased cost of the machine. The large armature reaction results in a much poorer regulation than that obtained with three phase alternators, and an increased amount of field copper is required, also larger exciting units. These items augment the cost so that the single phase machine is considerably more expensive than the three phase, of the same output and heating.

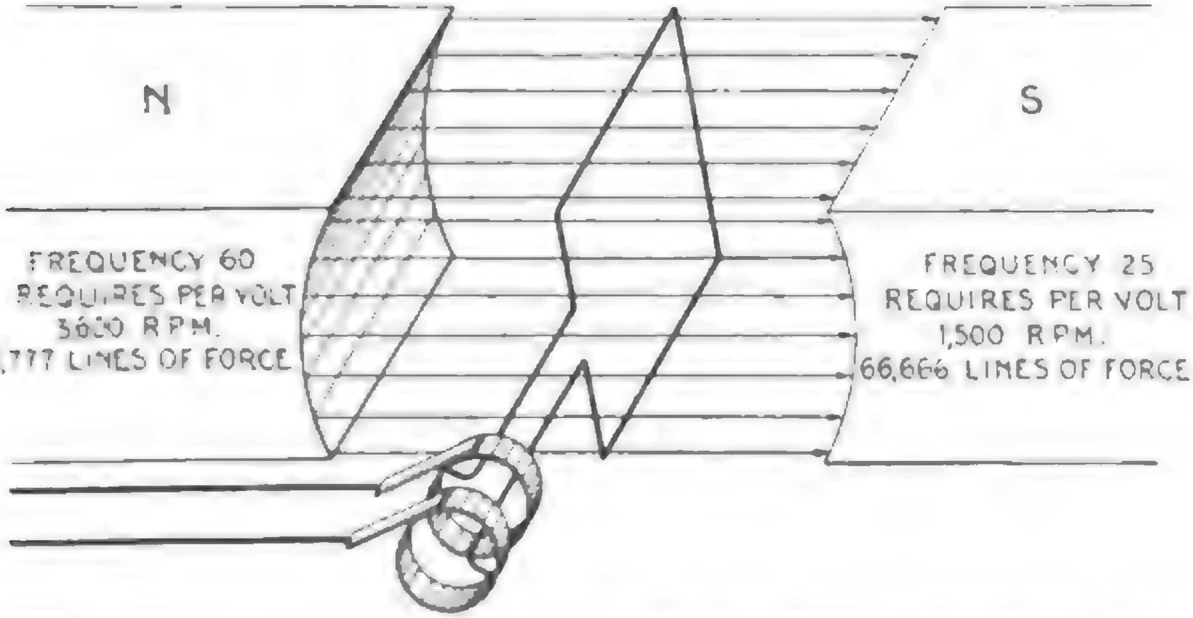


FIG. 2,149.—Elementary alternator developing one volt at frequencies of 60 and 25, **showing the effect of reducing the frequency.** Since for the same number of pole, the R.P.M. have to be decreased to decrease the frequency, increased flux is required to develop the same voltage. **Hence in construction,** low frequency machines require *larger magnets, increased number of turns in series on the armature coils, larger exciting units* as compared with machines built for higher frequency.

Ques. What factor increases the difficulties of single phase alternator construction?

Ans. The difficulties appear to increase with a *decrease* in frequency.

The adoption of any lower frequency than 25 cycles may result in serious difficulties in construction for a complete line of machine, especially those of the two or four pole turbine driven type where the field flux is very large per pole.

Monocyclic System.—In this system, which is due to Steinmetz, the alternator is of a special type. In construction, there is a **main** single phase winding an auxiliary or **teaser** winding connected to the central point of the main winding in quadrature therewith.

The teaser coil generates a voltage equal to about 25 per cent. of that of the main coil so that the pressure between the terminals of the main coil and the free end of the teaser is the resultant of the pressure of the two coils.

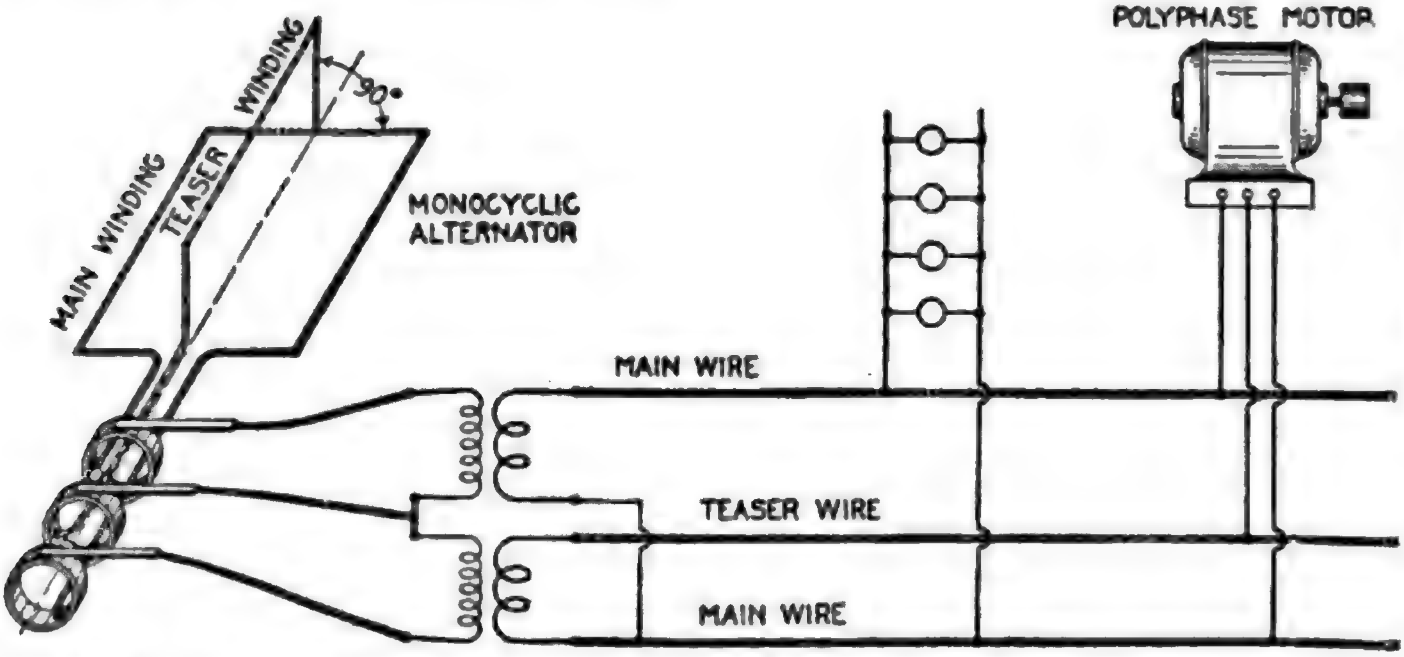


FIG. 2,150.—Diagram of monocyclic system, showing lighting and power circuits.

By various transformer connections it is possible to obtain a practically correct three phase relationship so that polyphase motors may be employed.

In this system, two wires leading from the ends of the single phase winding in the alternator supply single phase current to the lighting load, a third wire connected to the end of the teaser being run to points where the polyphase motors are installed as shown in fig. 2,150.

The monocyclic system is described at length in the chapter on alternators, Guide No. 5, pages, 1,156 to 1,159.

Two Phase Systems.—A two phase circuit is equivalent to two single phase circuits. Either four or three wire may be employed in transmitting two phase current, and even in the latter instance the conditions are practically the same as for single phase transmission, excepting the unequal current distribution in the three wires. Fig. 2,151 shows a two phase four wire system.

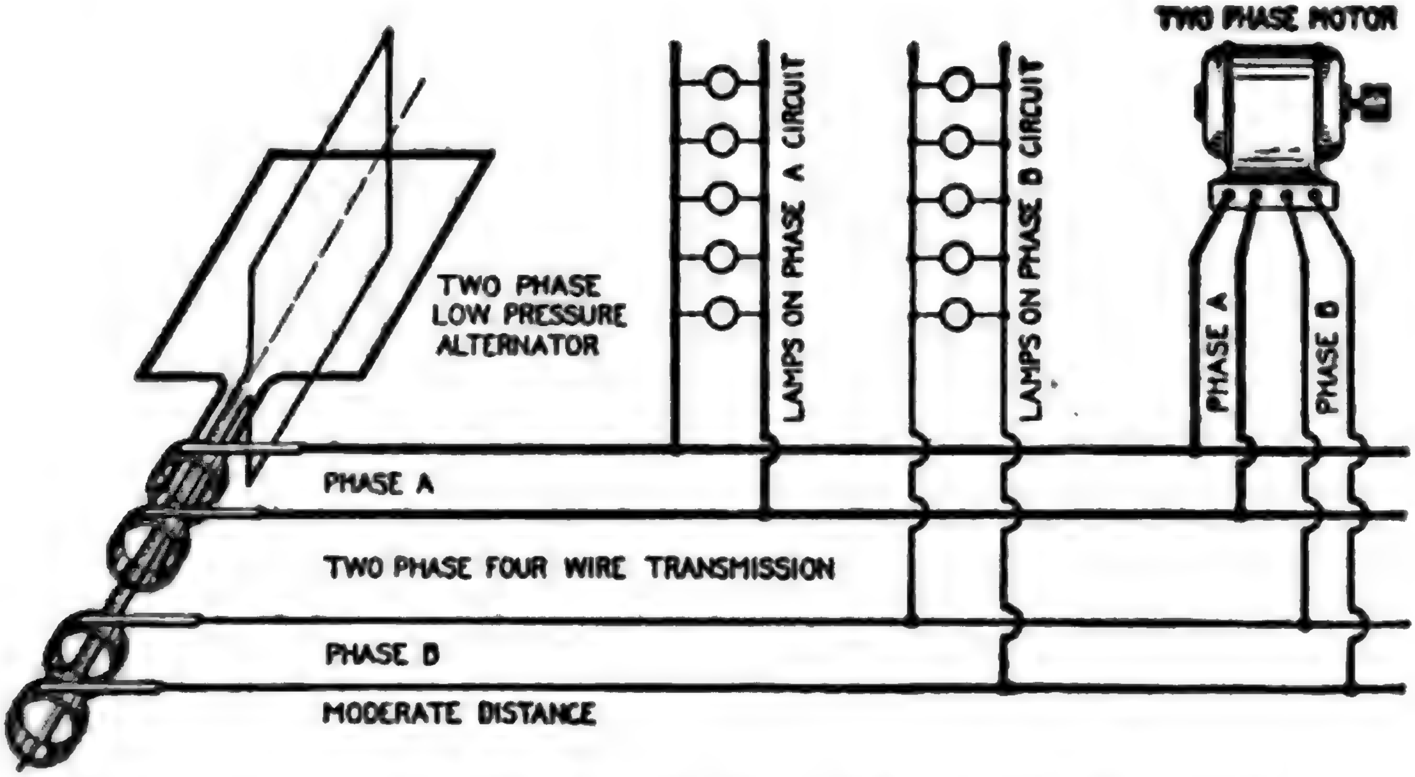

TWO PHASE MOTOR
LAMPS ON PHASE A CIRCUIT
LAMPS ON PHASE B CIRCUIT
TWO PHASE LOW PRESSURE ALTERNATOR
PHASE A
PHASE B
PHASE A
TWO PHASE FOUR WIRE TRANSMISSION
PHASE B
MODERATE DISTANCE

FIG. 2,151.—Diagram of two phase four wire system. It is desirable for supplying current for lighting and power. The arrangement here shown should be used only for lines of short or moderate length, because of the low voltage. Motors should be connected to a circuit separate from the lighting circuit to avoid drop on the latter while starting a motor.

Ques. For what service is the system shown in fig. 2,151 desirable?

Ans. It is adapted to supplying current for lighting and power at moderate or short distances.

Either 110 or 220 volts are ordinarily used which is suitable for incandescent lighting and for constant pressure arc lamps, the lamps being connected singly or two in pairs.

Ques. Where current for both power and light are obtained from the same source how should the circuits be arranged?

Ans. A separate circuit should be employed for each, in order to avoid the objectionable drop and consequent dimming of the lights due to the sudden rush of current during the starting of a motor.

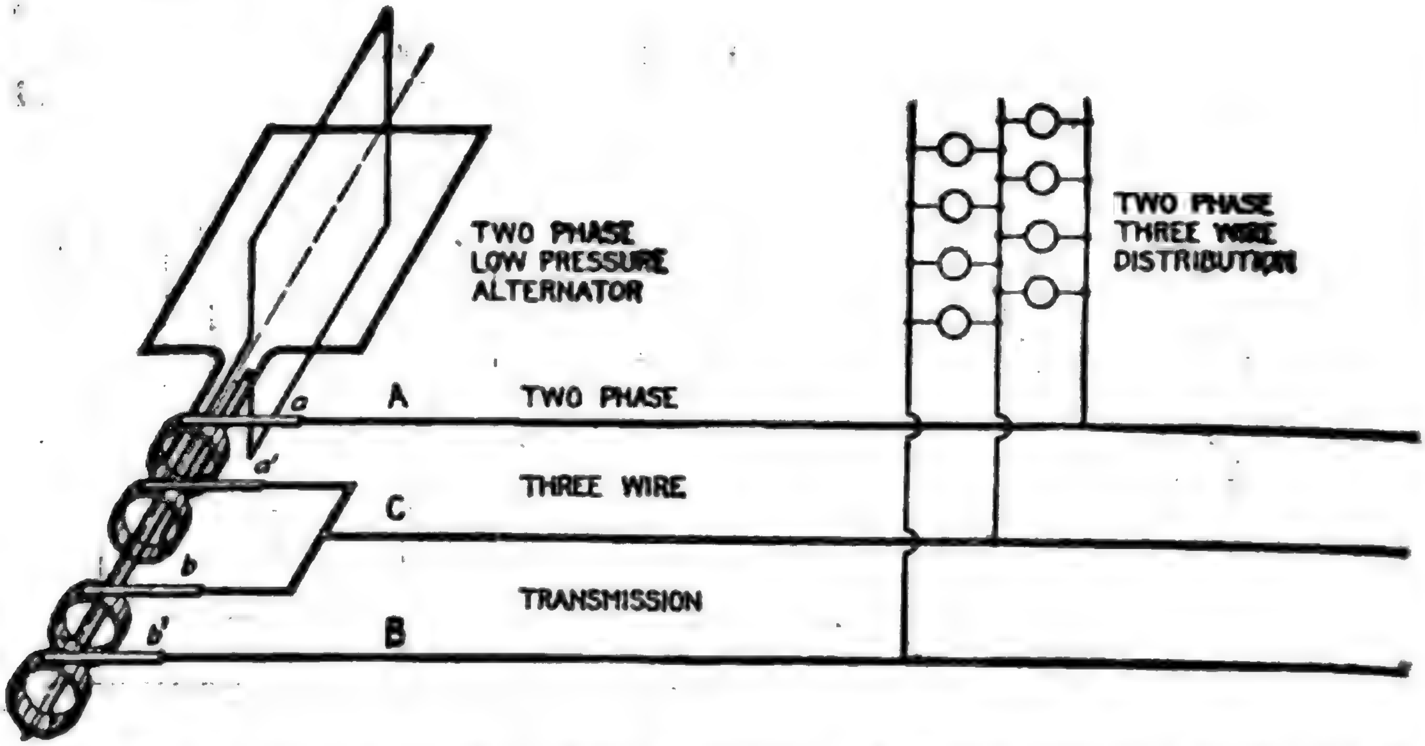


FIG. 2,152.—Diagram of two phase three wire system. A wire is connected to one end of each phase winding as at A and B, and a third wire C, to the other end of both phases as shown.

Disagreeable fluctuation of the lights are always met with when motors are connected to a lighting circuit and the effect is more marked with alternating current than with direct current, because most types of alternating current motor require a heavy current usually lagging considerably when starting. This not only causes a large drop on the line, but also reacts injuriously upon the regulation of transformers and alternators, their voltage falling much more than with an equal non-inductive load.

Ques. What voltages are ordinarily used on two phase lines of more than moderate length?

Ans. For transmission distances of more than two or three miles, pressures of from 1,000 to 2,000 volts or more are employed to economize in copper. For long distance transmission of over fifty miles, from 30,000 to 100,000 volts and over are used.

Ques. For long distance transmission at 30,000 to 40,000 volts, what additional apparatus is necessary?

Ans. Step up and step down transformers.

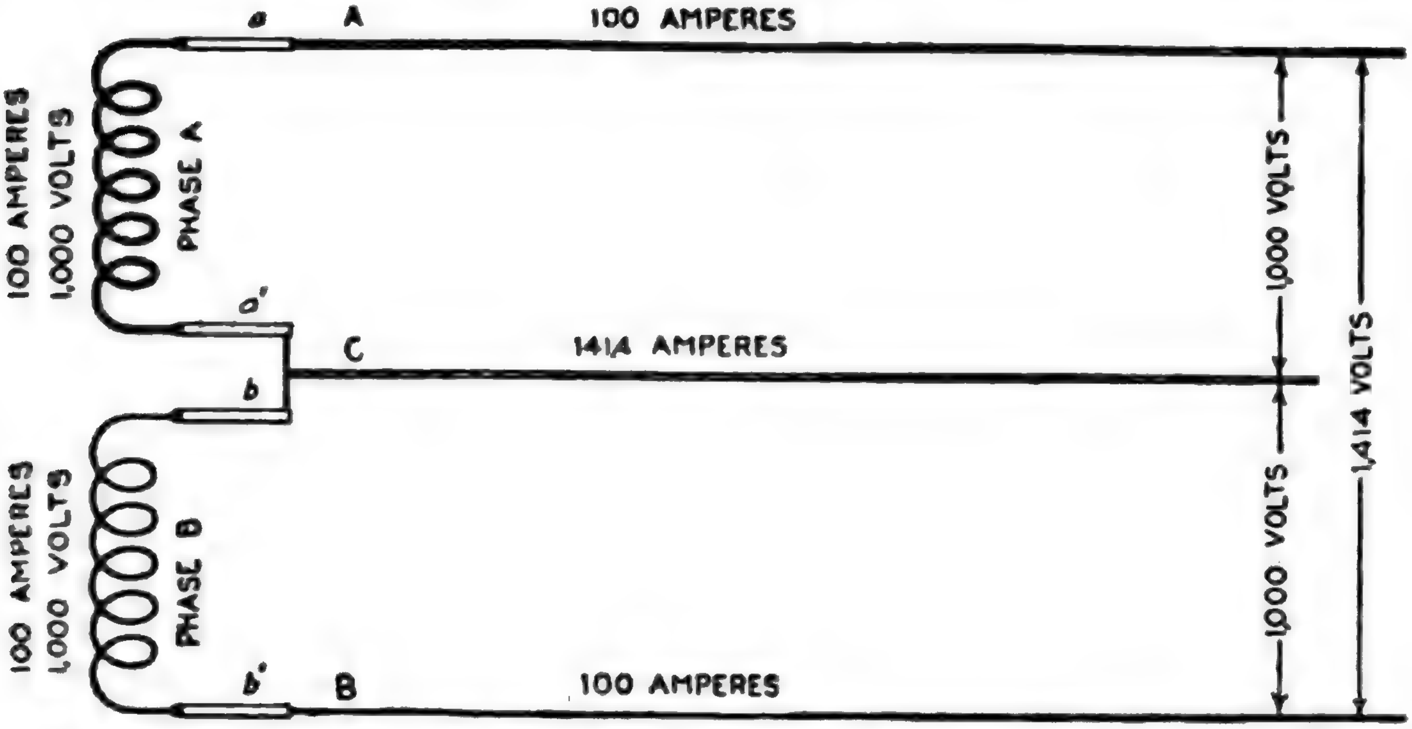

a
A
100 AMPERES
100 AMPERES
1,000 VOLTS
PHASE A
a'
C
1414 AMPERES
b
100 AMPERES
1,000 VOLTS
PHASE B
b'
B
100 AMPERES
1,000 VOLTS
1,000 VOLTS
1,414 VOLTS

FIG. 2,153.—Diagram illustrating two phase three wire transmission. The third wire C is attached to the connector between one end of phase A, and phase B windings.

Ques. Explain the method of transmitting two phase current with three wires.

Ans. The connections at the alternator are very simple as shown in fig. 2,152. One end of each phase winding is connected by the brushes *a* and *b'*, to one of the circuit wires, that is to A and B respectively. The other end of each phase winding is connected by a lead across brushes *a'* and *b*, to which the third wire C is joined.

The current and pressure conditions of this system are represented diagramatically in fig. 2,153. The letters correspond to those in fig. 2,152, with which it should be compared.

As shown in the figure each coil is carrying 100 amperes at 1,000 volts pressure. Since the phase difference between the two coils is 90°, the voltage between A and B is $\sqrt{2}=1.414$ times that between either A or B and the common return wire C.

The current in C is $\sqrt{2}=1.414$ times that in either outside wire A or B, as indicated.

Ques. How should the load on the two phase three wire system be distributed?

Ans. The load on the two phases must be carefully balanced.

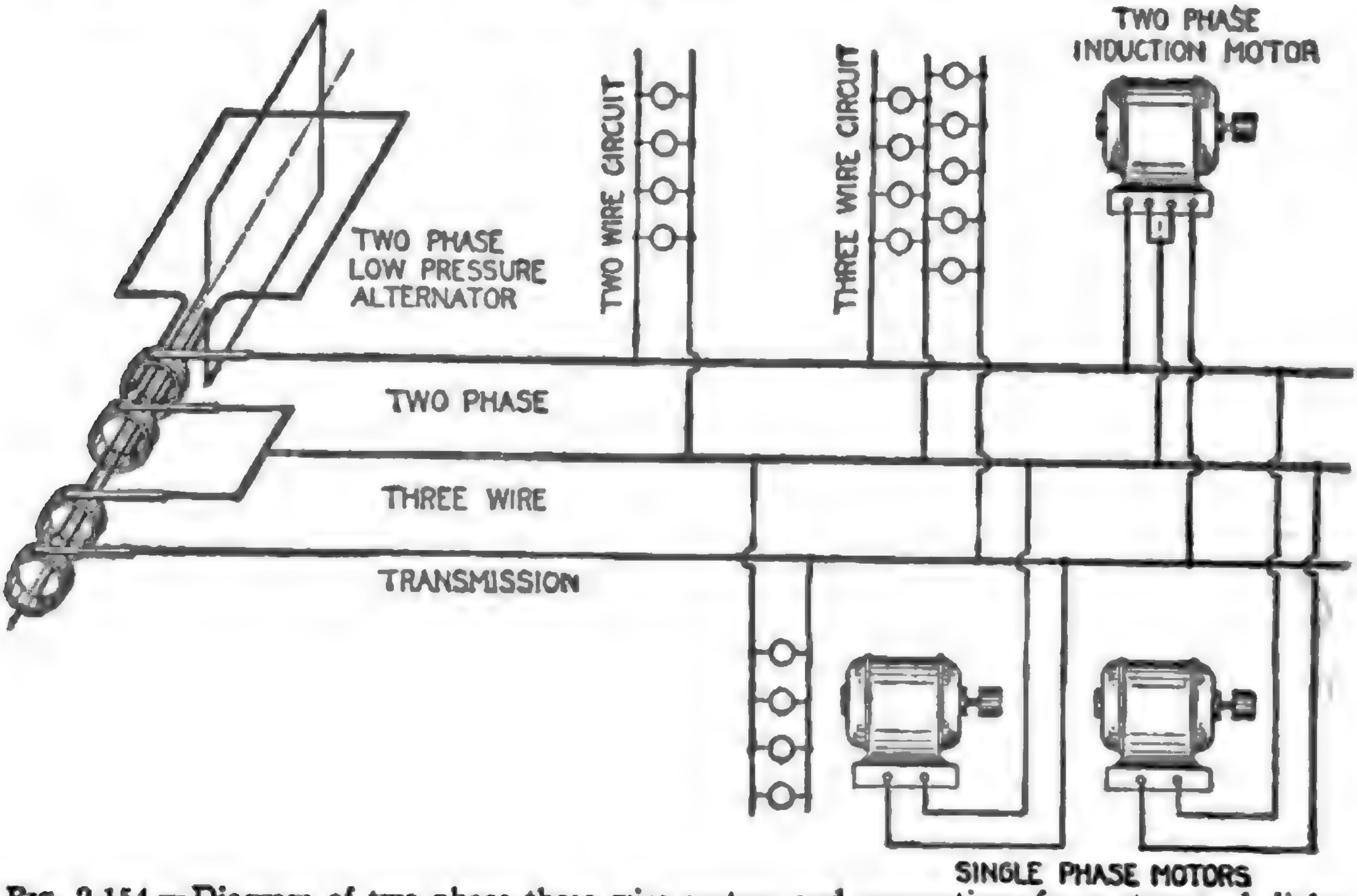

TWO PHASE INDUCTION MOTOR
TWO WIRE CIRCUIT
THREE WIRE CIRCUIT
TWO PHASE LOW PRESSURE ALTERNATOR
TWO PHASE
THREE WIRE
TRANSMISSION
SINGLE PHASE MOTORS

FIG. 2,154.—Diagram of two phase three wire system and connections for motors and lighting circuits.

Ques. Why should the power factor be kept high?

Ans. A high power factor should be maintained in order to keep the voltage on the phases nearly the same at the receiving ends.

Ques. How should single phase motors be connected and what precaution should be taken?

Ans. Single phase motors may be connected to either or both phases, but in such cases, no load should be connected between the outer wires otherwise the voltages on the different phases will be badly unbalanced.

Fig. 2,154 shows a two phase three wire system, with two wire and three wire distribution circuits, illustrating the connection for lighting and for one and two phase motors.

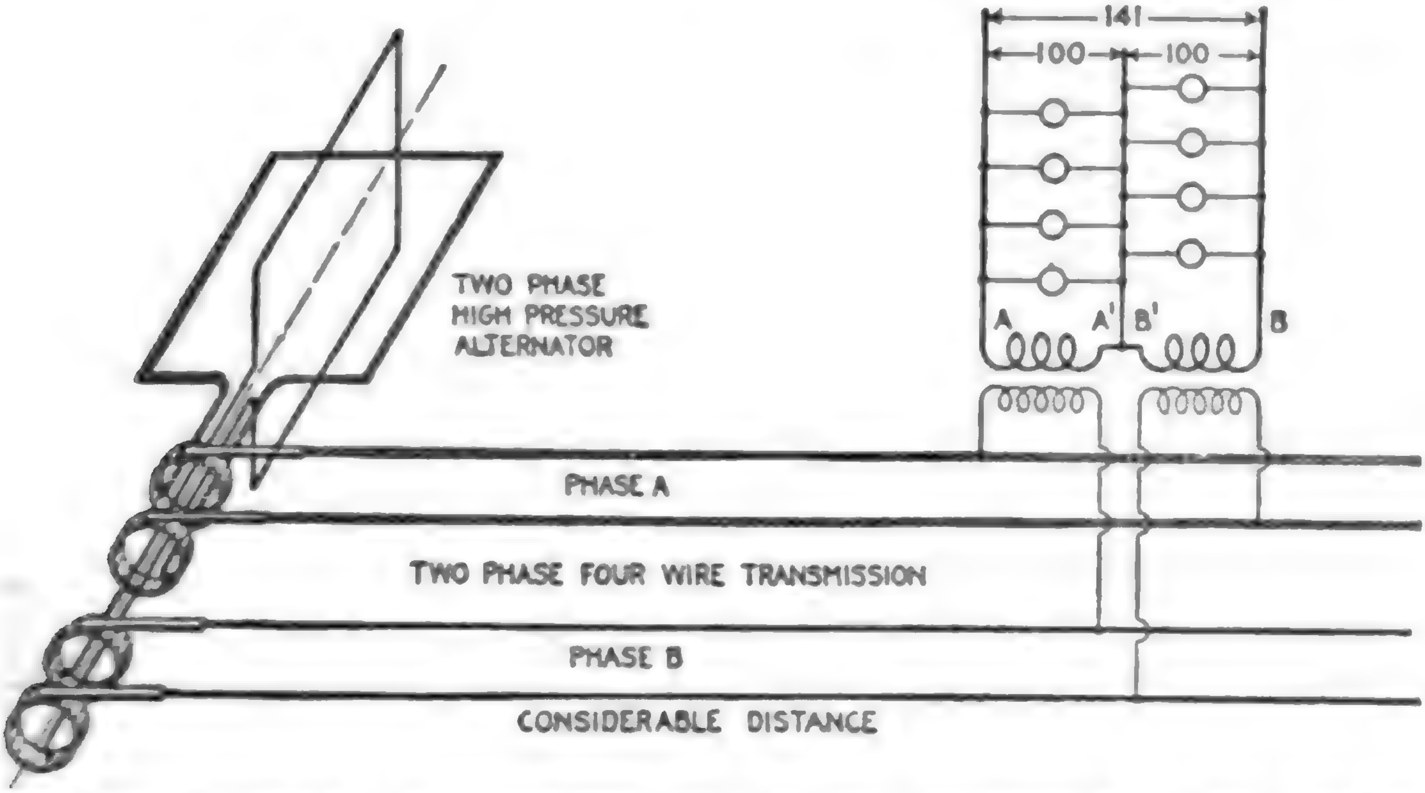


FIG. 2,155.—Diagram of two phase system with four wire transmission and three wire distribution. In the three wire circuits the relative pressures between conductors are as indicated; that is, the pressure between the two outer wires A and B is 141 volts, when the pressure between each cuter wire and the central is 100 volts.

Ques. Describe another method of transmission and distribution with two phase current.

Ans. The current may be transmitted on a four wire circuit and distributed on three wire circuit as in fig. 2,155.

The four wire transmission circuit is evidently equivalent to two independent single phase circuits.

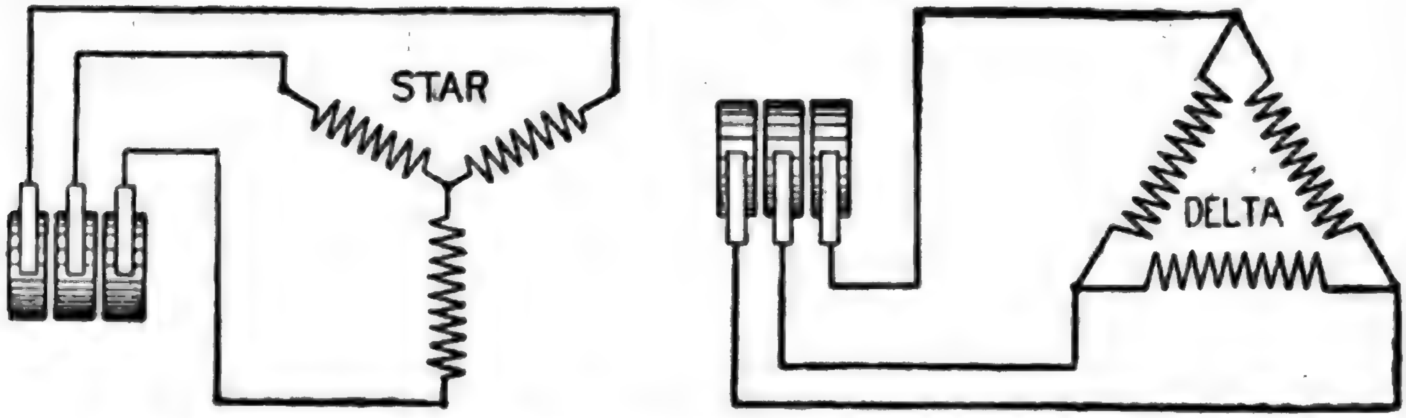
In changing from four to three wires, it is just as well to connect the two outside wires A and B together (fig. 2,152), as it is to connect *a'* and *b*. It makes no difference which two secondary wires are joined together, so long as the other wires of each transformer are connected to the outside wires of the secondary system.

Ques. For what service is the two phase three wire system adapted?

Ans. It is desirable for supplying current of minimum pressure to apparatus in the vicinity of transformers. It is more frequently used in connection with motors operating from the secondaries of the transformers.

Ques. How should the third or common return wire be proportioned?

Ans. Since the current in the common return wire is 41.4 per cent. higher than that in either of the other wires it must be of correspondingly larger cross section, to keep the loss equal.



FIGS. 2,156 and 2,157.—Conventional diagrams illustrating **star** and **delta** connected three phase alternator armatures.

Ques. What is the effect of an inductive load on the two phase three wire system and why?

Ans. It causes an unbalancing of both sides of the system even though the energy load be equally divided. The self-induction pressure in one side of the system is in phase with the virtual pressure in the other side, thus distorting the current distribution in both circuits.

Ques. Describe the two phase five wire system.

Ans. A two phase circuit may be changed from four to five wires by arranging the transformer connections as in fig. 2,158.

As shown, the secondaries of the transformers are joined in series and leads brought out from the middle point of each secondary winding and at the connection of the two windings, giving five wires.

With 1,000 volts in the primary windings and a step down ratio of 10 : 1, the pressure between A and C and C and E will be 100 volts and between the points and the connections B or D at the middle of the secondary coils, 50 volts.

The pressure across the two outer wires A and E is, as in the three wire system, $\sqrt{2}$ or 1.41 times that from either outer wire to the middle wire C, that is 141 volts.

The pressure across the two wires connected to the middle of the coils, that is, across B and D, is $50 \times \sqrt{2} = 70.5$ volts.

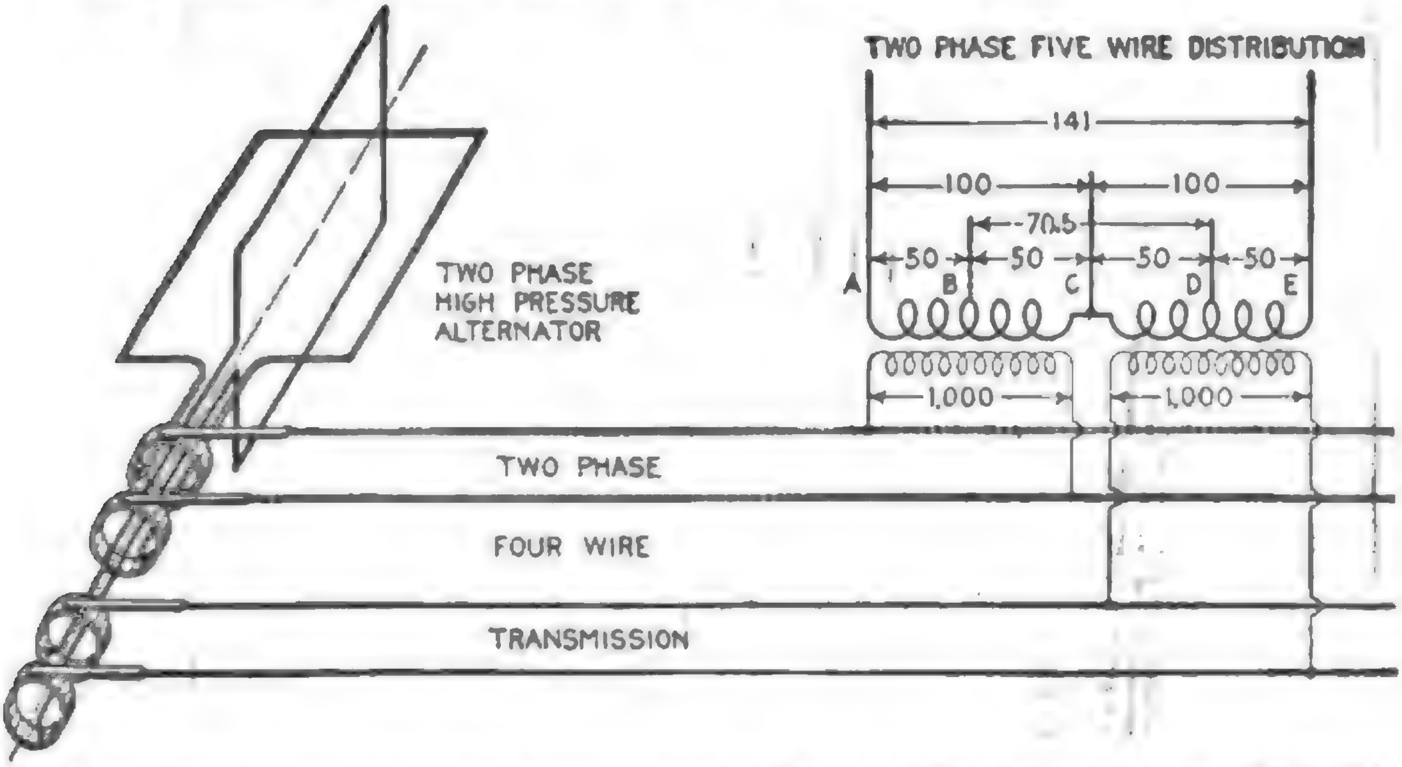

TWO PHASE FIVE WIRE DISTRIBUTION
141
100
100
70.5
50
50
50
50
A
B
C
D
E
1,000
1,000
TWO PHASE
HIGH PRESSURE
ALTERNATOR
TWO PHASE
FOUR WIRE
TRANSMISSION

FIG. 2.158.—Two phase four wire transmission and five wire distribution system. The relative pressures between the various conductors are indicated in the diagram.

Three Phase Systems.—There are various ways of arranging the circuit for three phase current giving numerous three phase systems.

1. With respect to the number of wires used they may be classified as

a. Six wire;
b. Four wire;
c. Three wire.

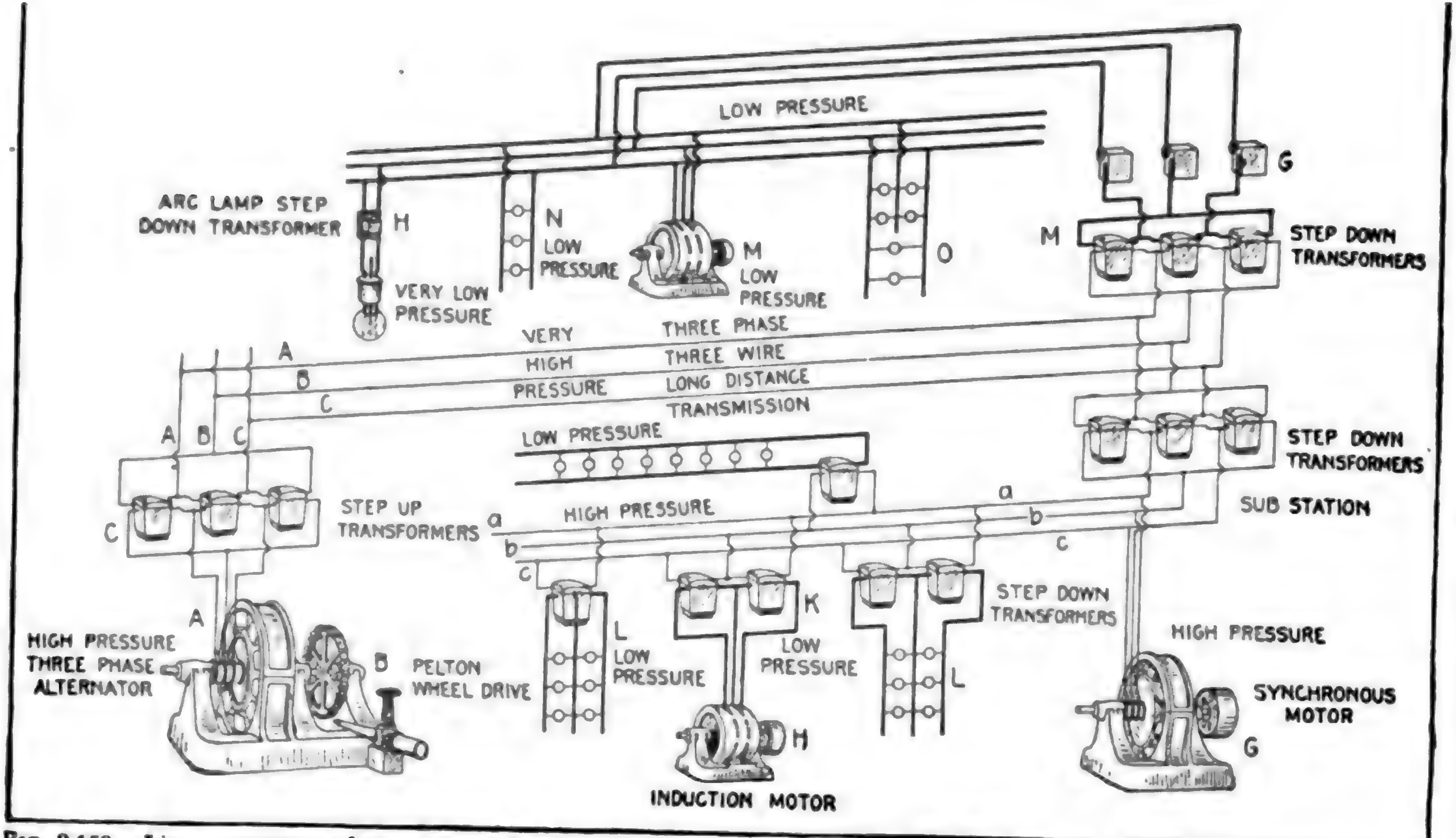

LOW PRESSURE
G
ARC LAMP STEP DOWN TRANSFORMER
H
N
LOW PRESSURE
M
LOW PRESSURE
O
M
STEP DOWN TRANSFORMERS
VERY LOW PRESSURE
VERY HIGH PRESSURE
THREE PHASE THREE WIRE LONG DISTANCE TRANSMISSION
A
B
C
A B C
LOW PRESSURE
STEP DOWN TRANSFORMERS
SUB STATION
C
STEP UP TRANSFORMERS
a
b
c
HIGH PRESSURE
K
L
STEP DOWN TRANSFORMERS
HIGH PRESSURE THREE PHASE ALTERNATOR
A
B
PELTON WHEEL DRIVE
LOW PRESSURE
LOW PRESSURE
L
HIGH PRESSURE
SYNCHRONOUS MOTOR
G
H
INDUCTION MOTOR

Fig. 2,159.—Line connections of three phase three wire long distance transmission, and distribution system. The three phase alternator A, is driven by the water wheel B, and furnishes current at say 2,200 volts plus sufficient pressure to compensate for line drop. With 1:10 step up transformers C, this would give a transmission pressure of 22,000 volts plus line drop. *It is this transformation that secures the* **copper economy** *of the system.* At the distribution end are the step down transformers; one set reducing the voltage down to 2,200 volts, and supplying current direct to the synchronous motor, and through another set of other step down transformers, as L and K, to lighting and power circuits at 220 volts. Another set of step down transformers M reduce the pressure directly to 120 volts for power and lighting, the pressure being regulated by the regulators G. Arc lamps with individual transformers further reducing the pressure to 50 volts are connected to this circuit as shown.

2. With respect to the connections, as

   a. Star;
   b. Delta;
   c. Star delta;
   d. Delta star.

The six wire system is shown in fig. 2,160. It is equivalent to three independent single phase circuits. Such arrangement would only be used in very rare instances.

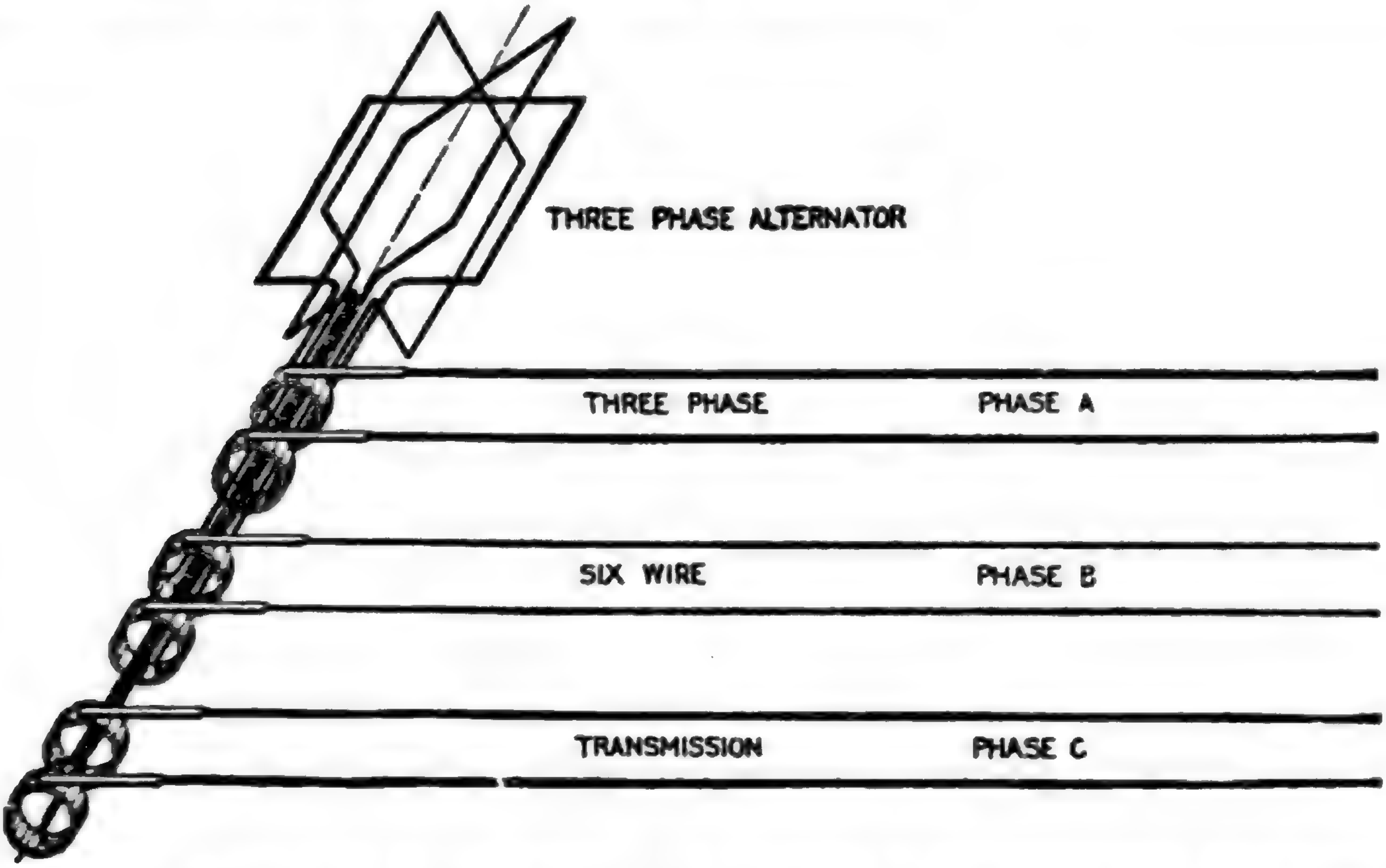
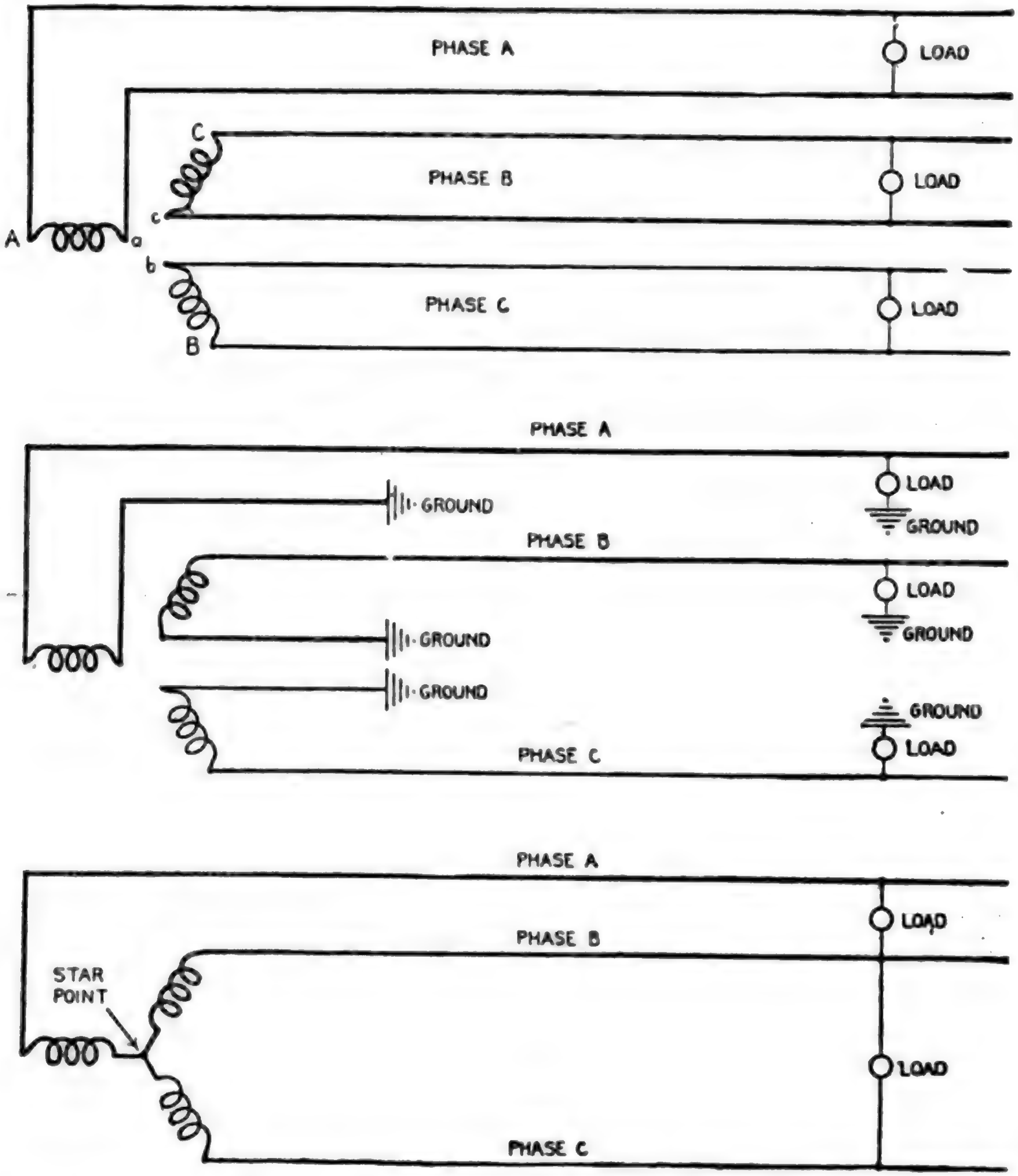


FIG. 2,160.—Three phase six wire system. It is equivalent to three independent single phase circuits and would be used only in very rare cases.

Ques. How can three phase current be transmitted by three conductors?

Ans. The arrangement shown in fig. 2,160 may be resolved into three single circuits with a common or grounded return.

When the circuits are balanced the sum of the current being zero no current will flow in the return conductor, and it may be dispensed with, thus giving the ordinary star or Y connected three wire circuit, as shown in fig. 2,163. The transformation from six to three wires being shown in figs. 2,161 to 2,163.

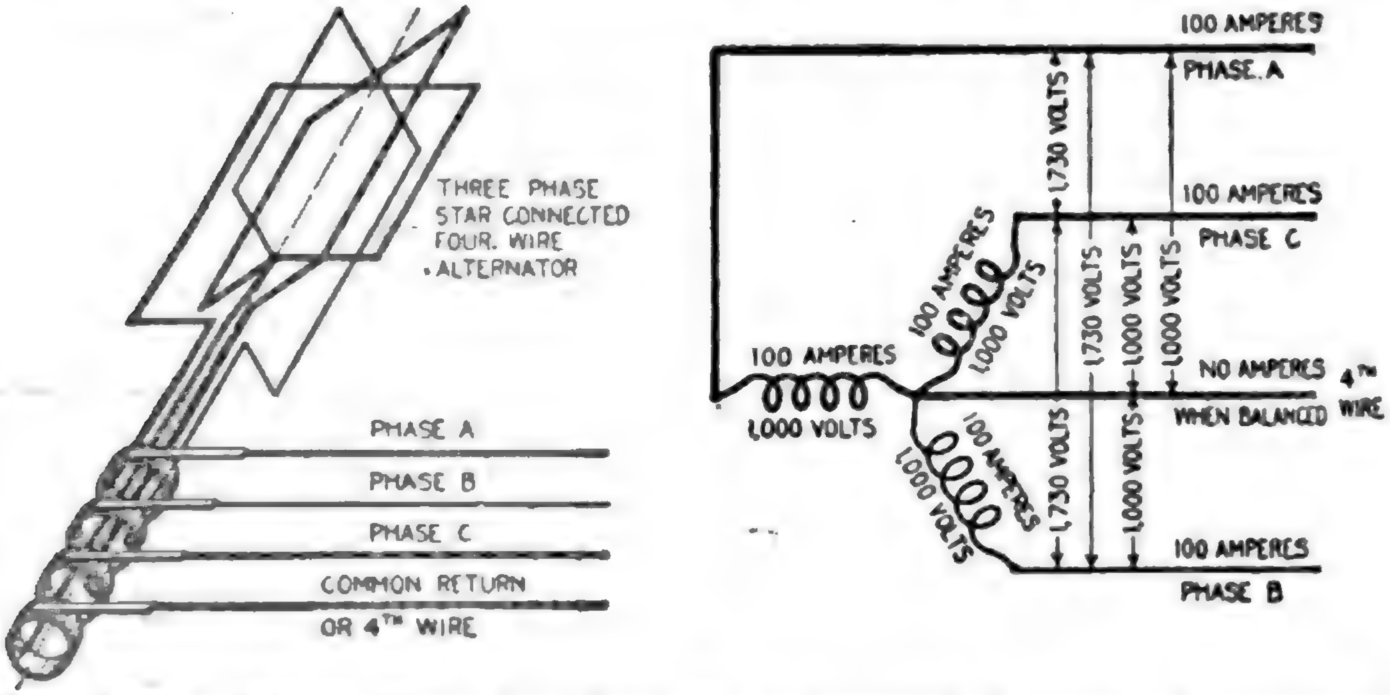

PHASE A
LOAD
C
PHASE B
LOAD
c
A
a
b
PHASE C
LOAD
B
PHASE A
LOAD
GROUND
GROUND
PHASE B
LOAD
GROUND
GROUND
GROUND
GROUND
PHASE C
LOAD
PHASE A
LOAD
PHASE B
STAR POINT
LOAD
PHASE C

Figs. 2,161 to 2,163.—Evolution of the three phase three wire system. Fig. 2,161 is a conventional diagram of the three phase six wire system shown in fig. 2,160. A wire is connected to both ends of each phase winding, giving six conductors, or three independent two wire circuits. In place of the wires running from A, B, and C, they may be removed and each circuit provided with a *ground* return as shown in fig. 2,162. The sum of the three currents being zero, or nearly zero, according to the degree of unbalancing, the ground return may be eliminated and the ends A, B, and C of the three phase winding connected, as in fig. 2,163, giving the so called *star point*.

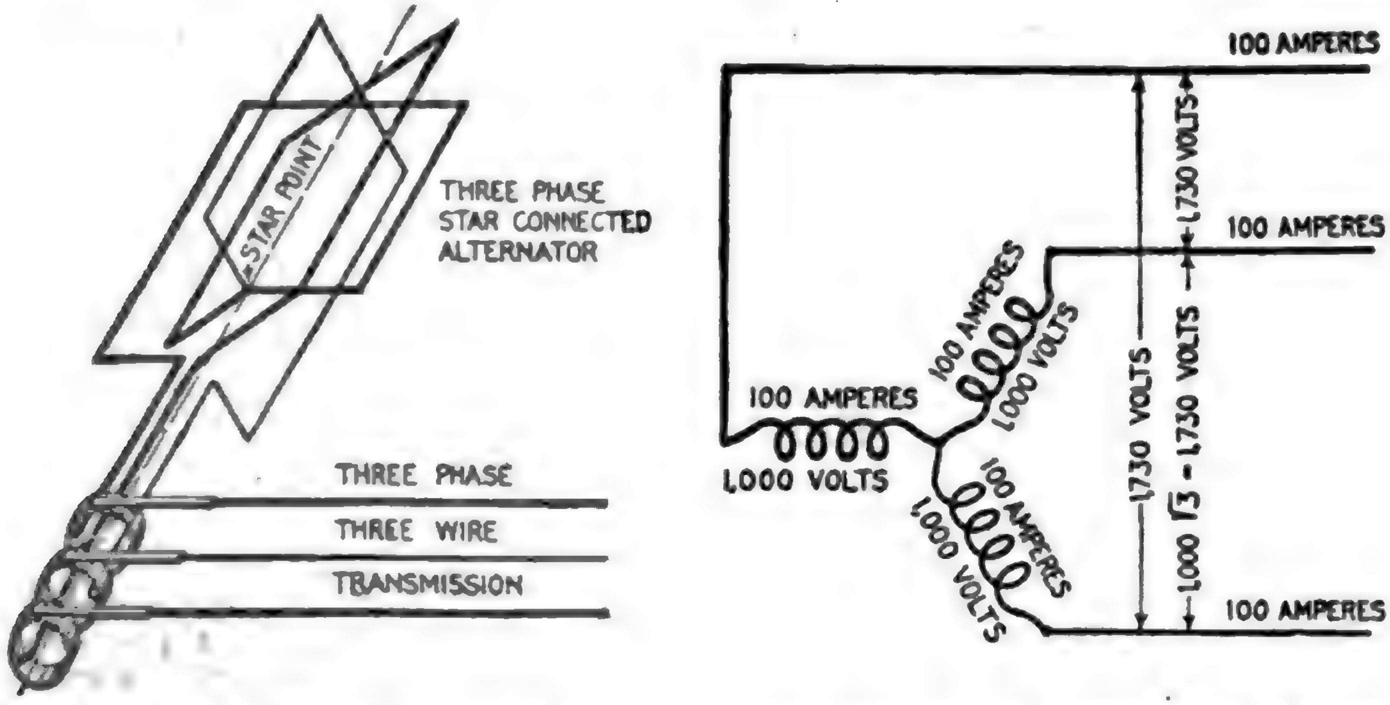
Fig. 2,166 is a view of an elementary three phase three wire star connected alternator.

Ques. What are the pressure and current relations of the star connected three wire system?

Ans. These are shown in the diagram, fig. 2,166 and 2,167


THREE PHASE
STAR CONNECTED
FOUR. WIRE
ALTERNATOR
PHASE A
PHASE B
PHASE C
COMMON RETURN
OR 4TH WIRE
100 AMPERES
PHASE A
1,730 VOLTS
100 AMPERES
PHASE C
100 AMPERES
1,000 VOLTS
1,730 VOLTS
1,000 VOLTS
1,000 VOLTS
100 AMPERES
1,000 VOLTS
NO AMPERES
WHEN BALANCED
4TH WIRE
100 AMPERES
1,000 VOLTS
1,730 VOLTS
1,000 VOLTS
100 AMPERES
PHASE B

FIGS. 2,164 and 2,165.—Three phase **four wire** *star connected* alternator and conventional diagram showing pressure and current relations.


STAR POINT
THREE PHASE
STAR CONNECTED
ALTERNATOR
THREE PHASE
THREE WIRE
TRANSMISSION
100 AMPERES
1,730 VOLTS
100 AMPERES
100 AMPERES
1,000 VOLTS
100 AMPERES
1,000 VOLTS
1,730 VOLTS
1,730 VOLTS
1,000 √3 = 1,730 VOLTS
100 AMPERES
1,000 VOLTS
100 AMPERES

FIGS. 2,166 and 2,167.—Three phase **star connected** alternator, and conventional diagram showing pressure relations.

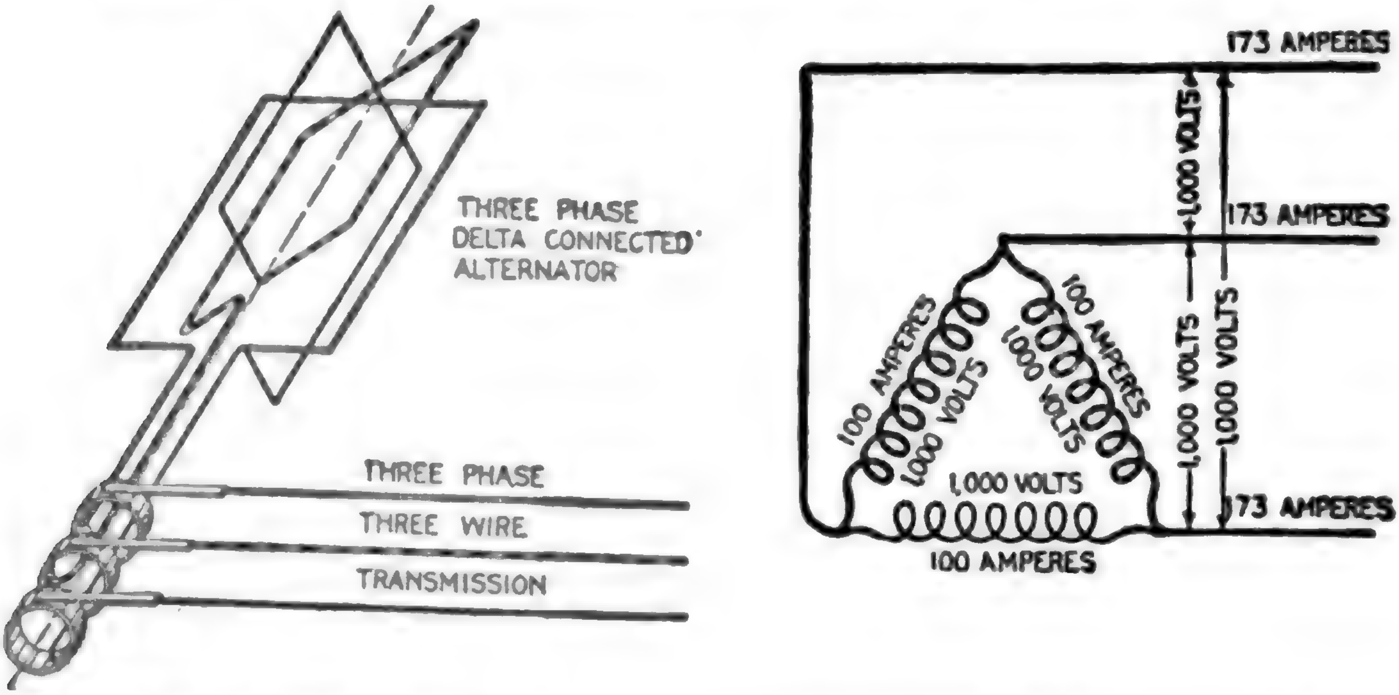
Assuming 100 amperes and 1,000 volts in each phase winding, the pressure between any two conductors is equal to the pressure in one winding multiplied by $\sqrt{3}$, that is $1{,}000 \times 1.732 = 1{,}732$ volts.

The current in each conductor is equal to the current in the winding, or 100 amperes.

Ques. Describe the delta connection.

Ans. In the delta connection, the three phase coils are connected together forming an endless winding, leads being brought out from these points.

Fig. 2,168 shows a delta connected three phase alternator, the pressure and current relation being given in fig. 2,169.


THREE PHASE
DELTA CONNECTED
ALTERNATOR
THREE PHASE
THREE WIRE
TRANSMISSION
173 AMPERES
1,000 VOLTS
173 AMPERES
100 AMPERES
1,000 VOLTS
100 AMPERES
1,000 VOLTS
1,000 VOLTS
1,000 VOLTS
1,000 VOLTS
173 AMPERES
100 AMPERES

Figs. 2,168 and 2,169.—Three phase **delta connected** alternator and conventional diagram showing pressure and current relations.

Ques. What are the pressure and current relations of the delta connected three wire system?

Ans. They are as shown in fig. 2,169.

Assuming 100 amperes and 1,000 volts in each phase winding, the pressure between any two conductors is the same as the pressure in the winding, and the current in any conductor is equal to the current in the winding multiplied by $\sqrt{3}$, that is $100 \times 1.732 = 173.2$ amperes, that is, disregarding the fraction, 173 amperes.

Ques. What are the relative merits of the star and delta connections?

Ans. The power output of each is the same, but the star connection gives a higher line voltage, hence smaller conductors may be used.

When it is remembered that the cost of copper conductors is inversely as the square of the voltage, the advantage of the Y connected system can be seen at once.

Assuming that three transformers are used for a three phase system of given voltage, each transformer, star connected, would be wound for $1 \div \sqrt{3} = 58\%$ of the given voltage, and for full current.

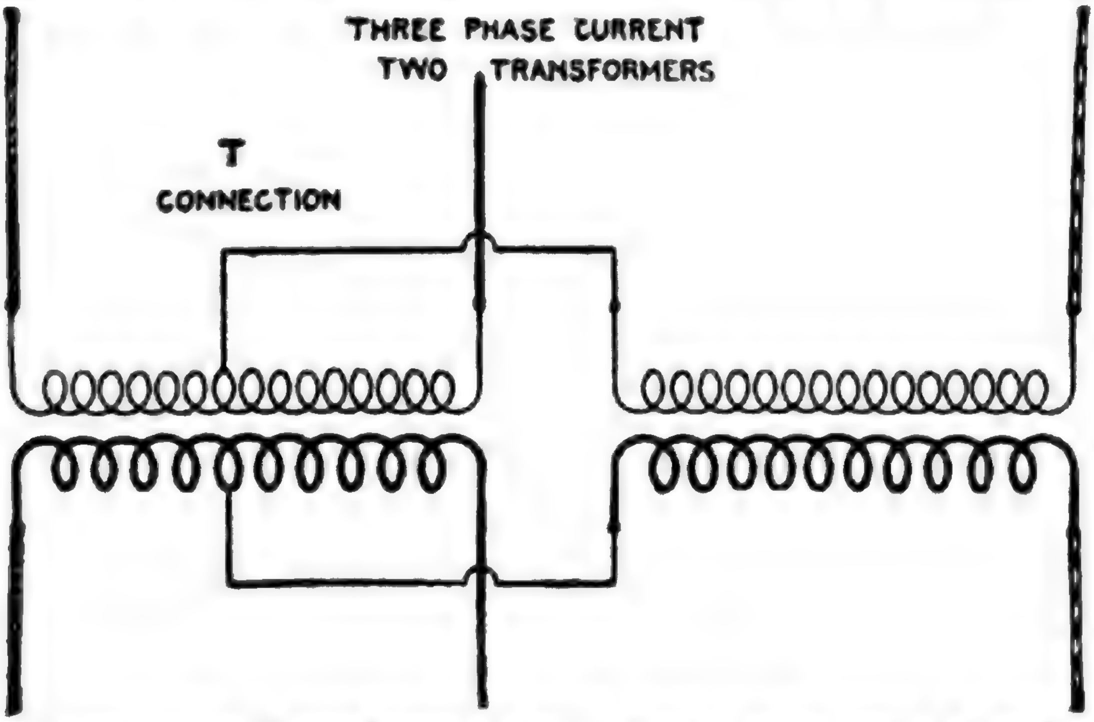


FIG. 2,170.—T connection of transformers in which three phase current is transformed with two transformers. The connections are clearly shown in the illustration. The voltage across one transformer is only 86.6% of that across the other, so that if each transformer be designed especially for its work one will have a rating of .866EI and the other EI. The combined rates will then be 1.866 as compared with 1.732 EI for three single phase transformers connected either star or delta.

For delta connection, the winding of each transformer is for 58% of the current. Accordingly the turns required for star connection are only 58% of those required for delta connection.

Ques. What is the objection to the star connection for three phase work?

Ans. It requires the use of three transformers, and if anything happen to one, the entire set is disabled.

Ques. Does this defect exist with the delta connection?

Ans. No.

One transformer may be cut out and the other two operated at full capacity, that is at ⅔ the capacity of the three.

Ques. Describe the T connection.

Ans. In this method two transformers are used for transforming three phase current. It consists in connecting one end of both windings of one transformer to the middle point of like windings of the other transformer as in fig. 2,170.

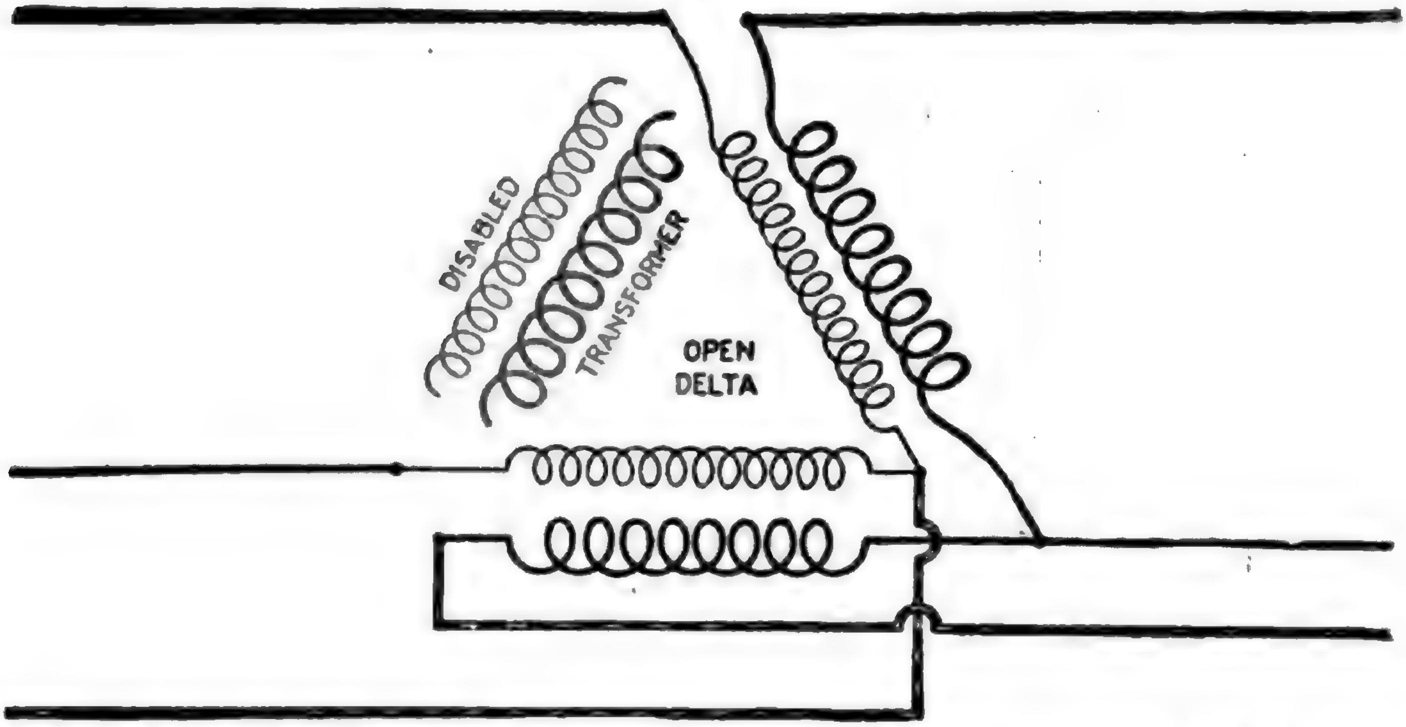


Fig. 2,171.—Open delta connection or method of connecting two transformers in delta for three phase transformation. It is used when one of the three single phase delta connected transformers becomes disabled.

Ques. What is the open delta connection?

Ans. It is a method of arranging the connections of a bank of three delta connected transformers when one becomes disabled as in fig. 2,171.

Change of Frequency.—There are numerous instances where it is desirable to change from one frequency to another, as for instance to join two systems of different frequency which may supply the same or adjacent territory, or, in the case of a low frequency installation, in order to operate incandescent lights satisfactorily it would be desirable to increase the frequency for such circuits. This is done by motor generator sets, the motor taking its current from the low frequency circuit.

Synchronous motors are generally used for such service as the frequency is not disturbed by load changes; it also makes it possible to use the set in the reverse order, that is, taking power from the high frequency mains and delivering energy at low frequency.

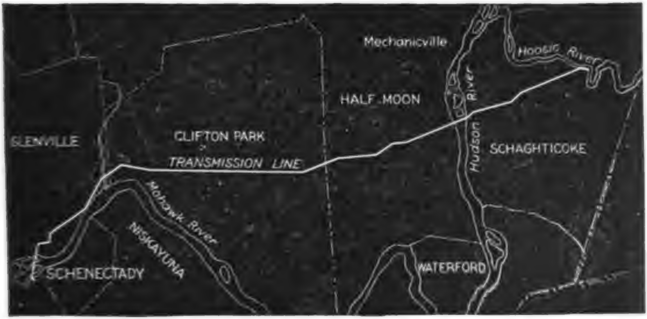


FIG. 2,172.—Course of the Schaghticoke-Schenectady transmission line of the Schenectady Power Co. This transmission line carries practically the entire output of the Schaghtiooke power house to Schenectady, N. Y., a distance of approximately 21 miles. The line consists of two separate three phase, 40 cycle, 32,000 volt circuits, each of 6,000 kw. normal capacity. These circuits start from opposite ends of the power house, and, after crossing the Hoosic River, are transferred by means of two terminal towers, fig. 2,173, to a single line of transmission towers. The two circuits are carried on these on opposite ends of the cross arms, the three phases being superimposed. The power house ends of the line are held by six short quadrangular steel lattice work anchor poles with their bases firmly embedded in concrete, the cables being dead ended by General Electric disc strain insulators. This equipment, together with the lightning arrester horn gaps and the heavy line outlet insulators mounted on the roof of the power house, is shown in fig. 2,174. While each circuit carries only 6,000 kw. under normal conditions, either is capable of carrying the entire output of the station; in this case, however, the line losses are necessarily augmented. This feature prevents any interruption of the service from the failure of one of the circuits. There are altogether 197 transmission towers, comprising several distinct types.

Ques. In the parallel operations of frequency changing sets what is necessary to secure equal division of the load?

Ans. The relative angular position of the rotating elements of motor and generator must be the same respectively in each set.

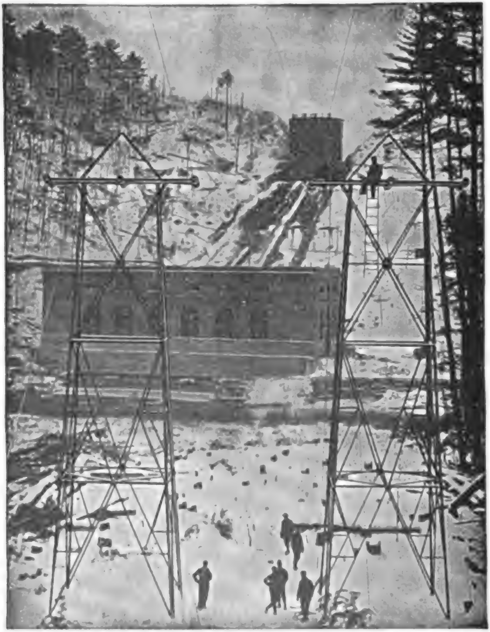


FIG. 2,173.—Beginning of Schaghticoke-Schenectady transmission line; view showing transfer towers with power house in background.

Ques. How is this obtained?

Ans. Because of the mechanical difficulty of accurately

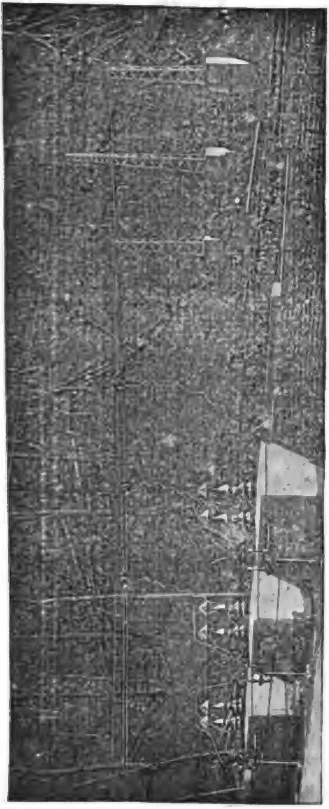


FIG. 2,174.—View from roof of power house of the Schaghticoke-Schenectady transmission line, showing anchor poles, strain insulators, lightning arrester horn gap and line entrance bushings.

locating the parts, the equivalent result is secured by arranging the stationary element in one of the two machines so that it can be given a small angular shift.

Transformation of Phases.—In alternating current circuits it is frequently desirable to change from one number of phases to another. For instance, in the case of a converter, it is less expensive and more efficient to use one built for six phases than for either two or three phases.

The numerous conditions met with necessitate various phase transformations, as

1. Three phase to one phase;

2. Three phase to two phase;

3. Two phase to six phase;
4. Three phase to six phase.

These transformations are accomplished by the numerous arrangements and combinations of the transformers.

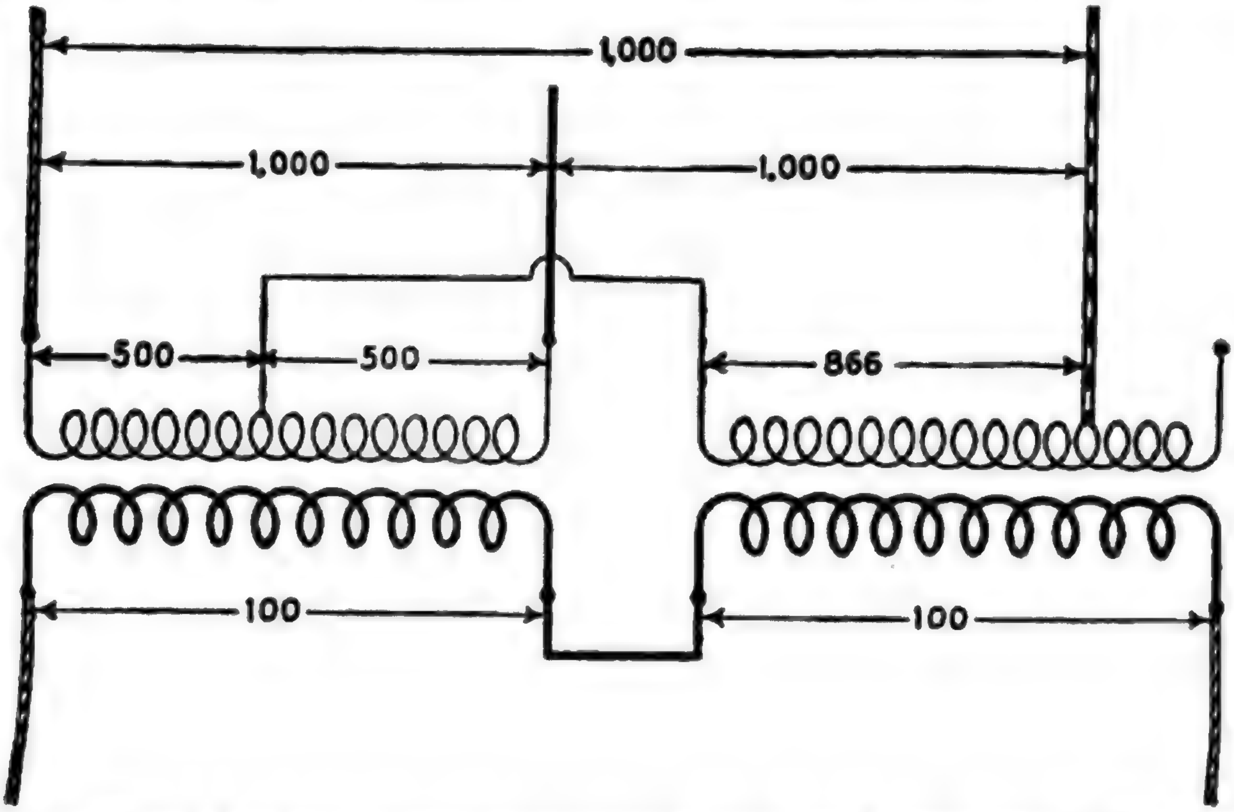


FIG. 2,175.—Three phase to one phase transformation with two transformers. The diagram shows the necessary connections and the relative pressures obtained.

Three Phase to One Phase.—This transformation may be accomplished by the use of two transformers connected as in fig. 2,175 in which one end of one primary winding is connected to the middle of the other primary winding and the second end of the first primary winding at a point giving 86.6 per cent. of that winding as shown. The two secondary windings are joined in series.

Three Phase to Two Phase.—The three phase system is universally used for long distance transmission, because it requires less copper than either the single or two phase systems.

For distribution, however, the two phase system presents certain advantages, thus, it becomes desirable at the distribution centers to change from three phase to two phase. This may be done in several ways.

Ques. Describe the Scott connection.

Ans. Two transformers are used, one having a 10:1 ratio, and the other, a $\frac{1}{2}\sqrt{3}$: 1, that is, an 8.66 : 1 ratio. The connections are arranged as in fig. 2,176.

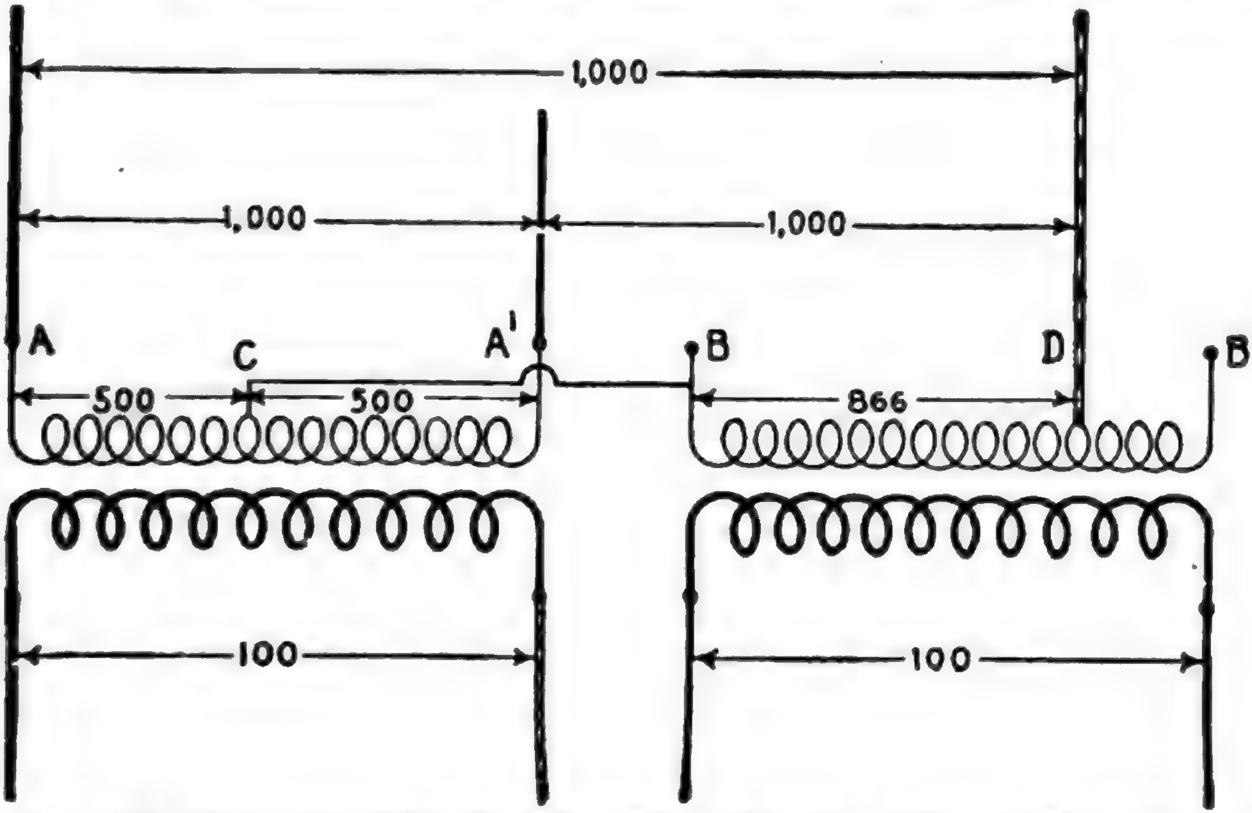


FIG. 2,176.—The Scott connection for transforming from three phase to two phase. In this method one of the primary wires B of the .866 ratio transformer is connected to the middle of the other primary as at C, the ends of which are connected to two of the three phase wires. The other phase wire is connected at D, the point giving the .866 ratio. The secondary wires are connected as shown.

It is customary to employ standard transformers having the ratios 10 : 1, and 9 : 1.

Ques. What names are given to the two transformers?

Ans. The one having the 10 : 1 ratio is called the **main** transformer, and the other with the 8.66 : 1 ratio, the **teaser** transformer.

In construction, the transformers may be made exactly alike so that either may be used as main or teaser.

In order that the connections may be properly and conveniently made, the primary windings should be provided with 50% and 86.6% taps.

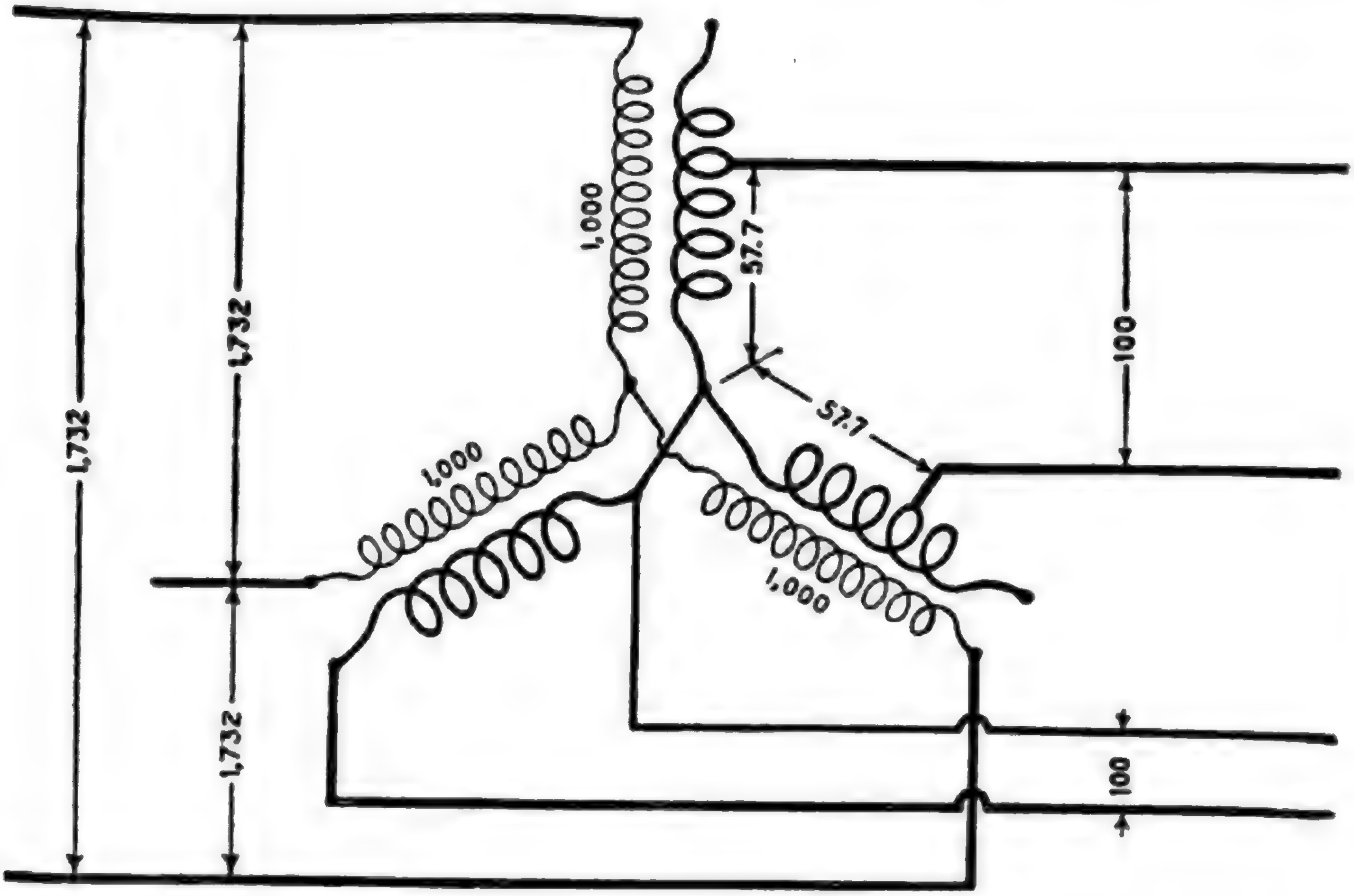


Fig. 2,177.—Three phase to two phase transformation with three star connected transformers. Two of the secondary windings are tapped at points corresponding to 57.7% of full voltage; these two windings are connected in series to form one secondary phase of voltage equal to that obtained by the other full secondary winding.

Ques. Describe another way of transforming from three to two phases.

Ans. The transformation may be made by three star connected transformers, proportioning the windings as in fig. 2,177, from which it will be seen that two of the secondary windings are tapped at points corresponding to 57.7 per cent. of full **oltage.**

Three Phase to Six Phase.—This transformation is usually made for use with rotary converters and may be accomplished in several ways. As these methods have been illustrated in the chapter on Converters (page 1,462), it is unnecessary to again discuss them here. Fig. 2,178, below shows the *diametrical* connection for transforming three phase to six phase.

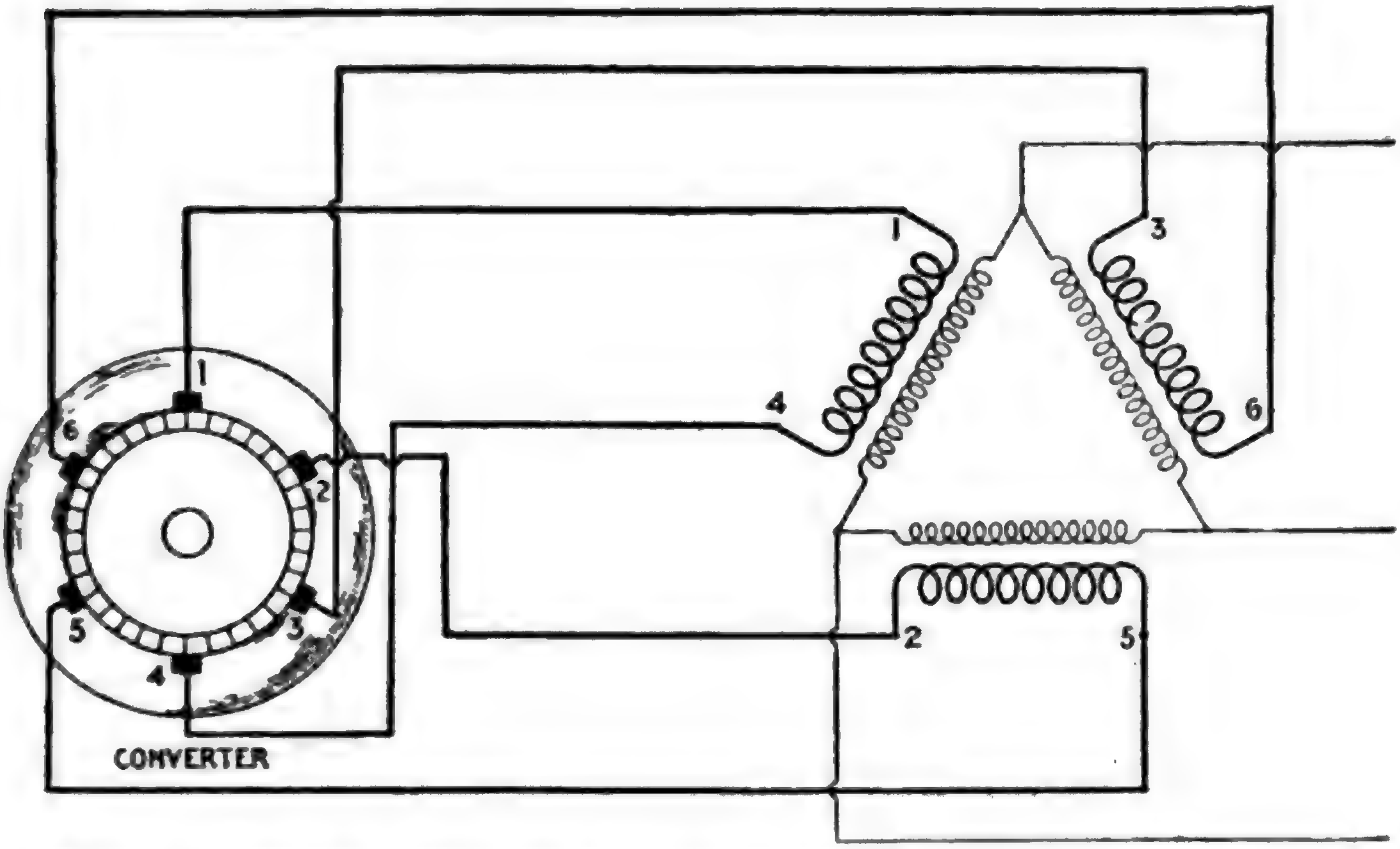


FIG. 2,178.—**Diagram of diametrical connection,** *three phase to six phase.* It is obtained *by bringing both ends of each secondary winding to opposite points on the rotary converter winding,* utilizing the converter winding to give the six phases. This transformation of phases may also be obtained with transformers having two secondary windings.

Alternating Current Systems.—The saving in the cost of transmission obtained by using alternating instead of direct current is not due to any difference in the characteristics of the currents themselves, but to the fact that in the case of alternating current very high pressures may be employed, thus permitting a given amount of energy to be transmitted with a relatively small current.

In the case of direct current systems, commutator troubles limit the transmission pressure to about 1,000 volts, whereas with alternating current it may be commercially generated at pressures up to about 13,000 and by means of step up transformers, transmitted at 110,000 volts or more.

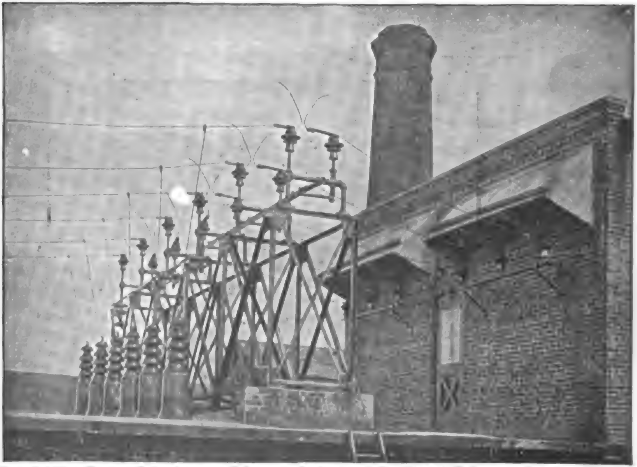


FIG. 2,179.—End of Schaghticoke-Schenectady transmission line at Schenectady; view showing entrance bushings and lightning arrester horn gaps.

Relative Weights of Copper Required by Polyphase Systems.—A comparison between the weights of copper required by the different alternating current systems is rendered quite difficult by the fact that the voltage ordinarily measured is not the maximum voltage, and as the insulation has to withstand the strain of the maximum voltage, the relative value of copper obtained by calculation depends upon the basis of comparison adopted.

As a general rule, the highest voltage practicable is used for long distance transmission, and a lower voltage for local distribution. Furthermore, some polyphase systems give a multiplicity of voltages, and the question arises as to which of these voltages shall be considered the transmission voltage.

If the transmission voltage be taken to represent that of the distribution circuit, and the polyphase system has as many independent circuits as there are phases, the system would represent a group of several single phase systems, and there would be no saving of copper. Under these conditions, if the voltage at the distant end be taken as the transmission voltage, and the copper required by a single phase two wire system as shown in fig. 2,180, be taken as the basis of comparison, the relative weights of copper required by the various polyphase systems is given in figs. 2,181 to 2,188.

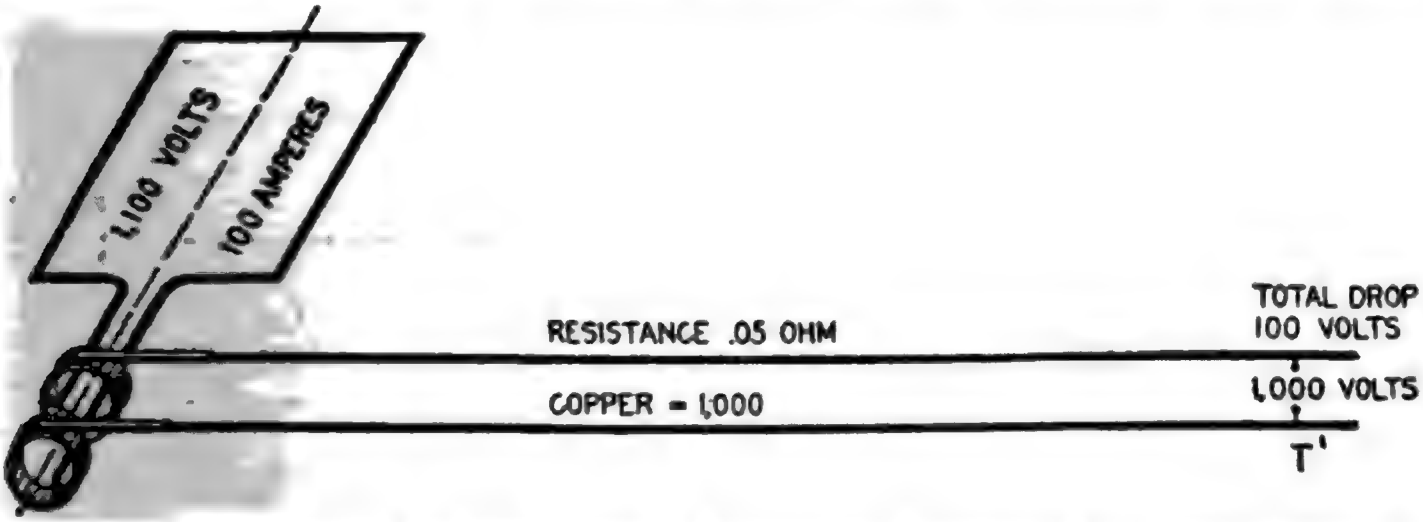
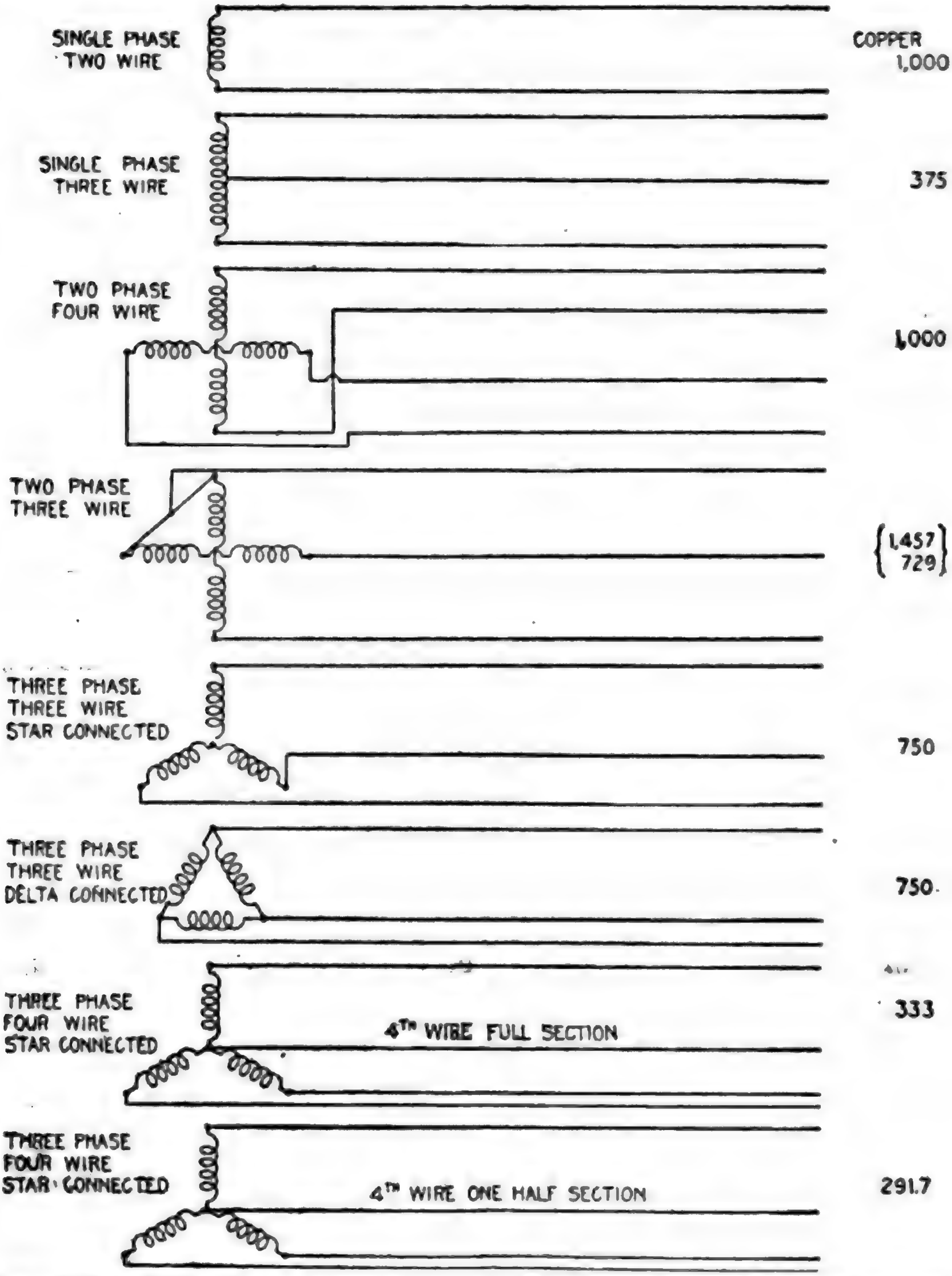


FIG. 2,180.—Single phase line, used as basis of comparison in obtaining the relative weights of copper required by polyphase systems, as indicated in figs. 2,181 to 2,188.

In the case represented in fig. 2,180, if the total drop on the line be 100 volts, the generated voltage must be 1,100 volts, and the resistance of each line must be 50 ÷ 1,000 = .05 ohms. Calculated on this basis, a two phase four wire system is equivalent to two single phase systems and gives no economy of copper in power transmission over the ordinary single phase two wire


SINGLE PHASE TWO WIRE
COPPER 1,000
SINGLE PHASE THREE WIRE
375
TWO PHASE FOUR WIRE
1,000
TWO PHASE THREE WIRE
1,457
729
THREE PHASE THREE WIRE STAR CONNECTED
750
THREE PHASE THREE WIRE DELTA CONNECTED
750
THREE PHASE FOUR WIRE STAR CONNECTED
4TH WIRE FULL SECTION
333
THREE PHASE FOUR WIRE STAR CONNECTED
4TH WIRE ONE HALF SECTION
291.7

Figs. 2,181 to 2,188.—Circuit diagrams showing relative copper economy of various alternating current systems.

system. This is the case also with any of the other two phase systems, except the two phase three wire system.

In this system two of the four wires of the four wire two phase system are replaced by one of full cross section.

The amount of copper required, when compared with the single phase system, will differ considerably according as the comparison is based on the highest voltage permissible for any given distribution, or on the minimum voltage for low pressure service.

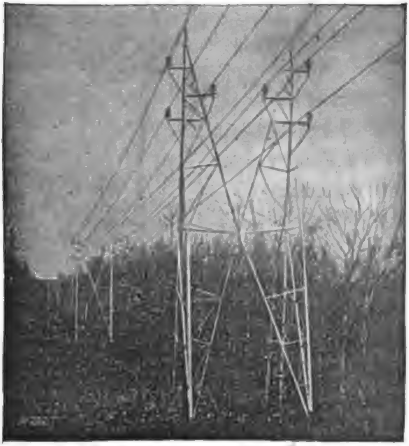


FIG. 2,189.—Twin circuit "aermotor" towers carrying 44,000 volt conductors (Southern Power Co.). These towers vary in height from 35 to 50 feet, and the circuits are transposed every 10 miles. The towers are assembled on the ground and erected by means of gin poles. They are normally spaced 500 feet apart with a sag of 5 feet 8 inches. The minimum distance between towers is 300 feet and the maximum 700 feet.

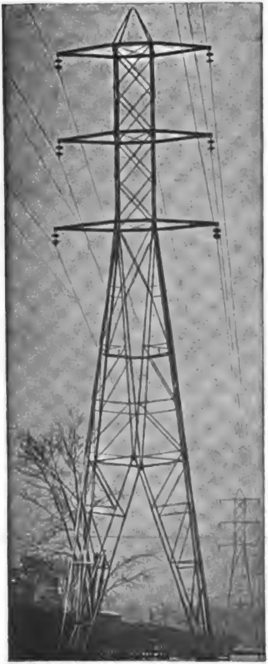
If E be the greatest voltage that can be used on account of the insulation strain, or for any other reason, the pressure between the other conductors of the two phase three wire system must be reduced to $E \div \sqrt{2}$.

The weight of copper required under this condition is 145.7% that of the single phase copper.

On the basis of minimum voltage, the relative amount of copper required is 72.9% that of the single phase system.

Figs. 2,187 and 2,188 are two examples of three phase four wire systems. The relative amount of copper required as compared with the single phase system depends on the cross section of the fourth wire. The arrangement shown in fig. 2,188, where the fourth wire is only half size, is used only for secondary distribution systems.

Choice of Voltage.—In order to properly determine the voltage for a transmission system there are a number of



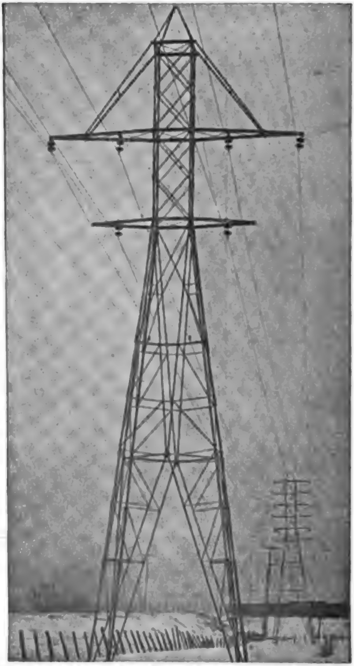


FIG. 2,190.—General Electric standard tower for high tension three phase transmission line.
FIG. 2,191.—General Electric transposition tower for high tension three phase transmission line

conditions which must be considered in order that the economy of the entire installation shall be a maximum.

The nature of the diversely various factors which affect the problem makes a mathematical expression difficult and unsatisfactory.

Ques. What is the relation between the cross sectional area of the conductors and the voltage?

Ans. For a given circuit, the cross sectional area of the conductors, or weight varies inversely as the voltage.

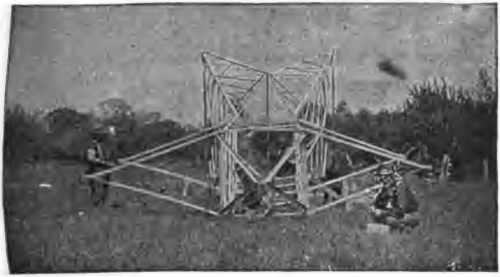


FIG. 2,192.—General Electric standard tower under construction.

Ques. Would the highest possible voltage then be used for a transmission line?

Ans. The most economical voltage depends on the length of the line and the cost of apparatus.

For instance, alternators, transformers, insulation and circuit control and lightning protection devices become expensive when manufactured for very high pressures. Hence if a very high pressure were used, it would involve that the transmission distance be great enough so that the extra cost of the high pressure apparatus would be offset by the saving in copper effected by using the high pressure.

In the case of the longest lines, from about 100 miles up, the saving in copper with the highest practicable voltage is so great that the increase in other expenses is rendered comparatively small.

In the shorter lines as those ranging in length from about one mile to 50 or 75 miles, the most suitable voltage must be determined in each individual case by a careful consideration of all the conditions involved. No fixed rule can be established for proper voltage based on the length, but the following table will serve as a guide:

FIG. 2,193.—Line of the Schenectady Power Company crossing the tracks of the Boston and Maine Railroad near Schaghticoke.

Usual Transmission Voltages

Length of line in miles	Voltage
1	500 to 1,000
1 to 2	1,000 to 2,300
2 to 3	2,300 to 6,600
3 to 10	6,600 to 13,200
10 to 15	13,200 to 22,000
15 to 20	22,000 to 44,000
20 to 40	44,000 to 66,000
40 o 60	66,000 to 88,000
60 to 100	88,000 to 110,000

Ques. What are the standard voltages for alternating current transmission circuits?

Ans. 6,600, 11,000, 22,000, 33,000, 44,000, 66,000, 88,000.

The amount of power to be transmitted determines, in a measure, the limit of line voltage. If the most economical voltage considered from the point of view of the line alone, be somewhere in excess of 13,200, step up transformers must be employed, since the highest voltage for which standard alternators are manufactured is 13,200. In a given case, the saving in conductor by using the higher voltage may be more than offset by the increased cost of transformers, and the question must be determined for each case.

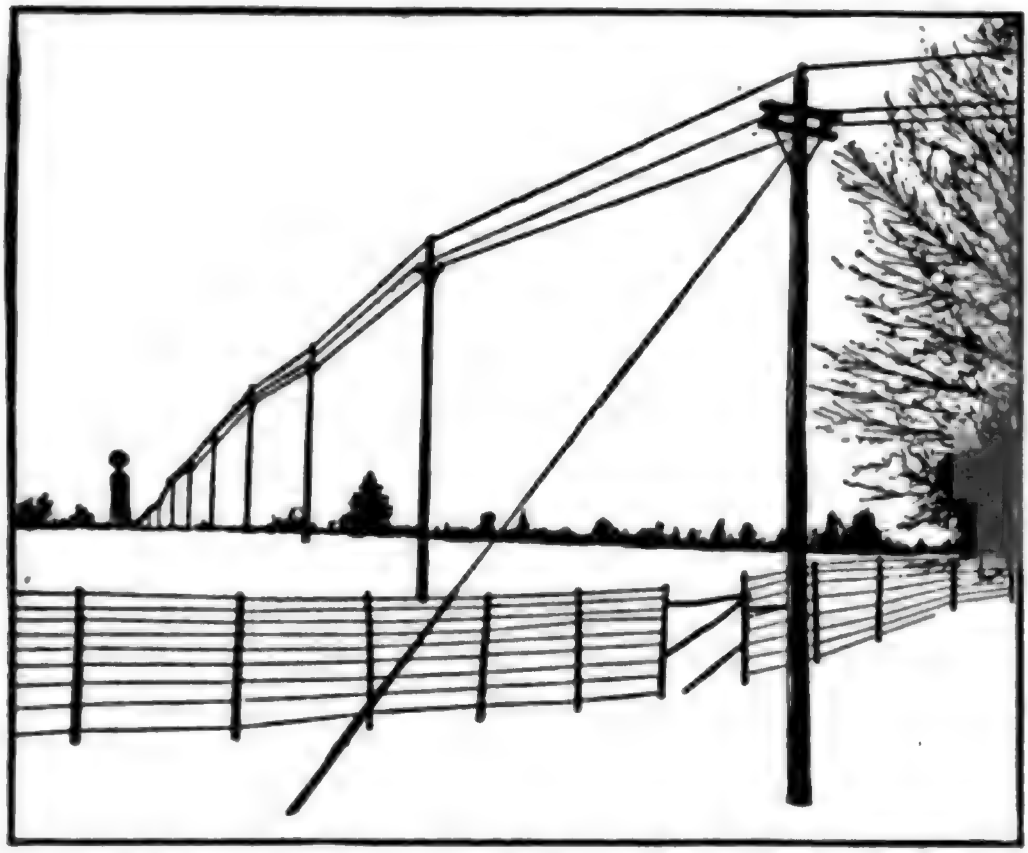
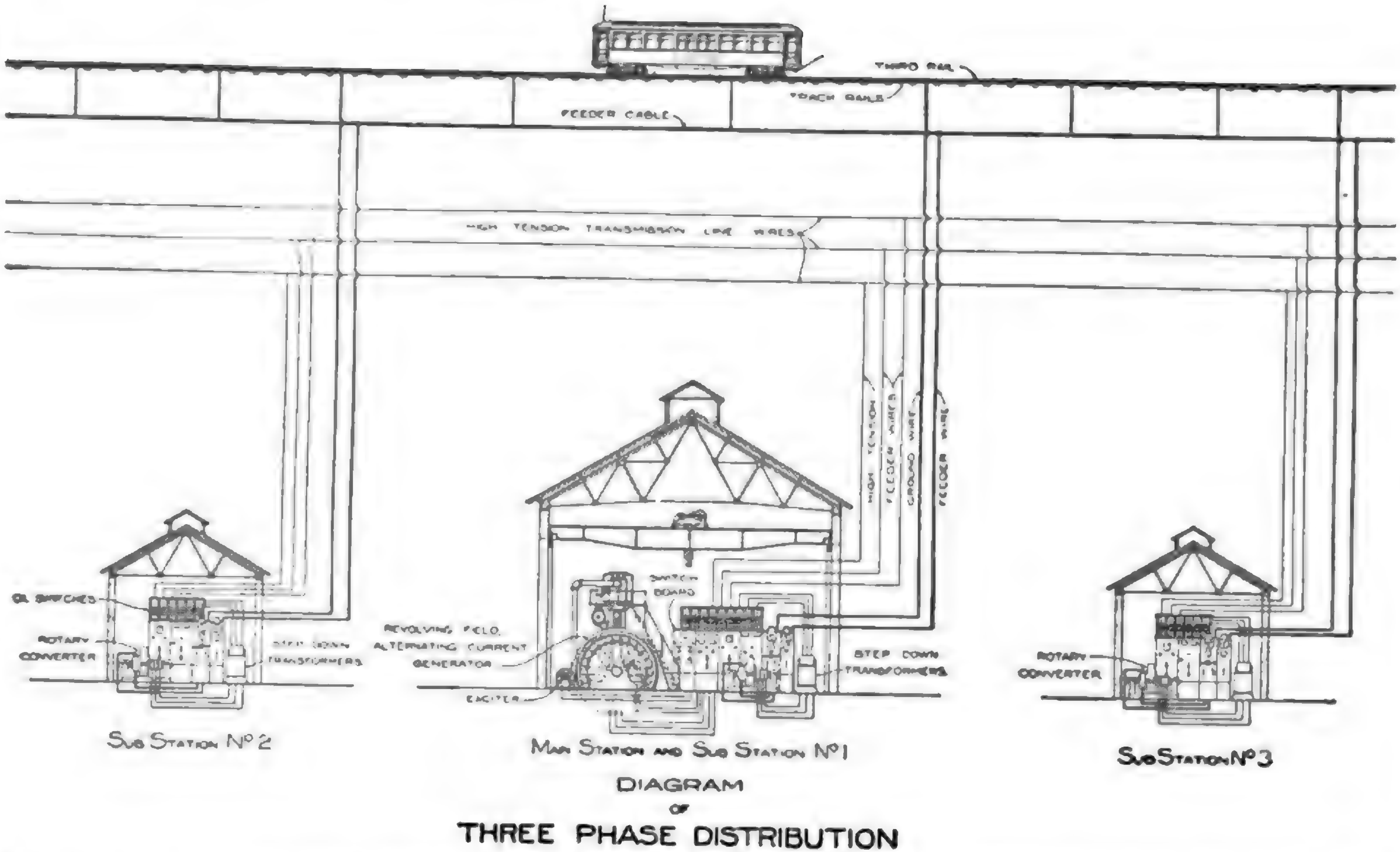


FIG. 2,194.—View of a three phase, 2,300 volt, 60 cycle line at Chazy, N. Y. The current is transmitted at the alternator voltage 2¼ miles over the single circuit pole line. The poles are of cedar with fir cross arms, and are fitted with pin insulators. They are from 35 to 40 feet high and are spaced at an average of about 120 feet. The conductors are bare copper wire No. 00 B. & S. The alternators consist of one 50 kw., and one 100 kw. General Electric machines.

Ques. What are the standard transformer ratios?

Ans. **Multiples of 5 or 10.**


THIRD RAIL
TRACK RAILS
FEEDER CABLE
HIGH TENSION TRANSMISSION LINE WIRES
HIGH TENSION
FEEDER WIRES
GROUND WIRE
FEEDER WIRE
OIL SWITCHES
ROTARY CONVERTER
STEP DOWN TRANSFORMERS
SWITCH BOARD
REVOLVING FIELD ALTERNATING CURRENT GENERATOR
EXCITER
STEP DOWN TRANSFORMERS
ROTARY CONVERTER
SUB STATION Nº 2
MAIN STATION AND SUB STATION Nº 1
SUB STATION Nº 3
DIAGRAM
OF
THREE PHASE DISTRIBUTION

FIGS. 2,195 to 2,197.—Diagram showing electric railway system. Three phase current is generated at the main station where it passes to **step up** transformers to increase the pressure a suitable amount for economical transmission. At various points along the railway line are *sub-stations*, where the three phase current is reduced in pressure to 500 or 600 volts by **step down** transformers, and converted into direct current by rotary converters. The relatively low pressure direct current is then conveyed by "feeders" to the rails, this resulting in a considerable saving in copper.

Mixed Current Systems.—It is often desirable to transmit electrical energy in the form of alternating current, and distribute it as direct current or vice versa.

Such systems may be classed as mixed current systems. The usual conversion is from alternating current to direct current because of the saving in copper secured by the use of alternating current in transmission, especially in the case of long distance lines. Such conversion involves the use of a rotary converter, motor generator set, or rectifier, according to the conditions of service.

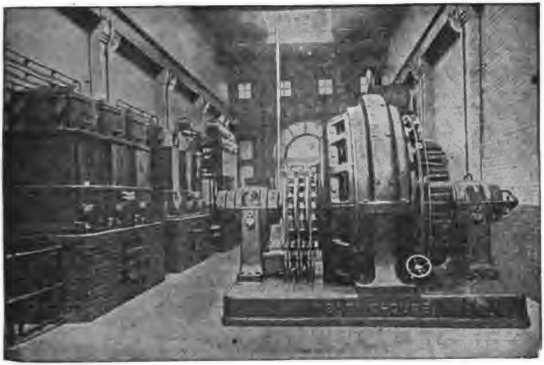


FIG. 2,198.—Example of converter sub-station, showing the Brooklyn Edison Co. Madison sub-station. The transformers are seen on the left, the converter shown at the right is a Westinghouse synchronous booster rotary converter, consisting of a standard rotary converter in combination with a revolving armature alternator mounted on the same shaft with the converter and having the same number of pole. *The function of the machine is to* **convert** and **regulate** *the pressure.* By varying the field excitation of the alternator, the A.C. voltage impressed on the rotary converter proper can be increased or decreased as desired. Thus, the D.C. voltage delivered by the converter is varied accordingly. This type of converter is well adapted for any application for which a relatively wide variation, either automatic or non-automatic, in direct current voltage is necessary. Also especially for serving incandescent lighting systems where considerable voltage variation is required for the compensation of drop in long feeders, for operation in parallel with storage batteries and for electrolytic work where extreme variations in voltage are required by changes in the resistance of the electrolytic cells.

The suburban trolley forms a good example of a mixed system, in which alternating current is generated at the *central station* and transmitted to *sub-stations*, where it is transformed to low pressure, and converted into direct current for use on the line. Fig. 2,195 shows the interior of a sub-station of this kind.

Ques. What direct current pressure is usually employed on traction lines?

Ans. 500 volts.

Ques. Mention another important service performed by a mixed system.

Ans. If the generator furnish alternating current it must be converted into direct current in order to charge storage batteries.

CHAPTER LVI

AUXILIARY APPARATUS

For the proper control of the alternating current in any of the numerous systems described in the previous chapter, various devices, which might be classed as "auxiliary apparatus," are required. These may be grouped into several divisions, according to the nature of the duty which they perform, as

1. Switching devices;
    - *a.* Ordinary switches;
    - *b.* Oil break switches;
    - *c.* Remote control switches.
2. Current or pressure limiting devices;
    - *a.* Fuses;
    - *b.* Reactances;
    - *c.* Circuit breakers;
    - *d.* Relays.
3. Lightning protection devices;
    - *a.* Air gap arresters;
    - *b.* Multi-gap arresters;
    - *c.* Horn gap arresters;
    - *d.* Electrolytic arresters;
    - *e.* Vacuum tube arresters;
    - *f.* Choke coils;
    - *g.* "Static" interrupters.

4. Regulating devices;

    a. Induction voltage regulators;
    b. Variable ratio transformer regulators
        - drum type;
        - dial type;
    c. Compensation shunts;
    d. Pole type regulators;
    e. Small feeder voltage regulators;
    f. Automatic voltage regulators;
    g. Line drop compensators;
    h. Starting compensators;
    i. Star delta switches.

5. Power factor regulating devices;

    a. Condensers;
    b. Synchronous condensers.

6. Indicating devices;

    a. Moving iron instruments
        - plunger type;
        - inclined coil type;
        - magnetic vane type;
    b. Hot wire instruments;
    c. Induction instruments
        - shielded pole type;
        - repulsion type;
    d. Dynamometers;
    e. Instrument transformers;
    f. Watthour meters
        - commutator type;
        - induction type;
        - Faraday disc type;
    g. Frequency indicators
        - synchronous motor type;
        - resonance type;
        - induction type;
    h. Synchronism indicators
        - lamp type;
        - voltmeter type;
        - resonance type;
        - rotating field type;
    i. Power factor indicators
        - wattmeter type;
        - rotating field type;
    j. Ground detectors;
    k. Earth leakage cut outs;
    l. Oscillographs.

CHAPTER LVII

SWITCHING DEVICES

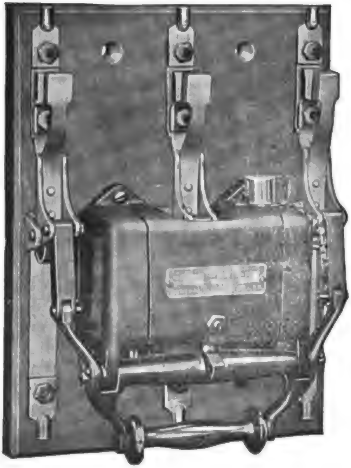
A switch is *a piece of apparatus for making, breaking, or changing the connections in an electric circuit.*

The particular form and construction of any switch is governed by the electrical conditions under which it must operate.

Since the electric current cannot be **stopped instantly** *when the circuit in which it is flowing, is broken,* **an arc is formed** *as the switch contacts separate;* this tends to burn the contacts, and to short circuit, the severity of such action depending on the voltage and the proximity of the switch terminals. Accordingly in switch design, provision must be made to counteract these tendencies. Thus,

1. The contacts should separate along their entire length, rather than at a point;
2. The terminals should be far enough apart and properly protected to prevent short circuiting of the arcs;
3. The break should be quick;
4. The gap should be surrounded by the proper medium (air or oil) to meet the requirements of the electrical conditions.

A great variety of switches have been introduced to suit the different requirements. Knife switches are used for low pressure service, the multiple break form being used where it is desired to reduce the arcing distance.



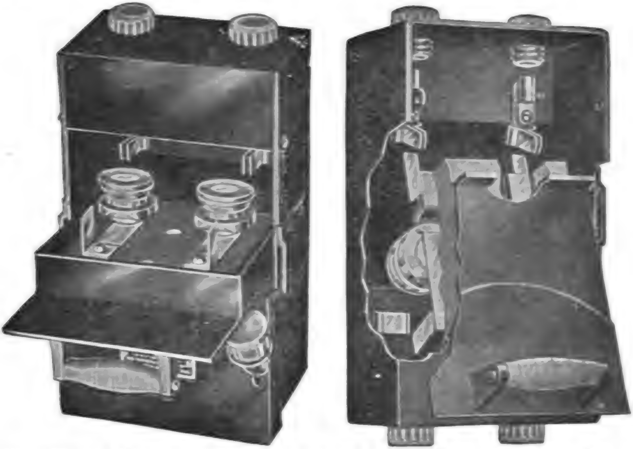
Ques. How should single throw switches be installed?

Ans. They should open downward so gravity will keep them open.

FIGS. 2,199 and 2,200.—General Electric triple pole solenoid operated, single throw remote control switch, and push button switch for operating same. Switch is a self-contained unit with two sets of contacts, main laminated copper brushes, and carbon auxiliary contacts to take the arc on breaking the circuit. The main brushes are so made that each lamination makes an end on contact with the switch blade without any tendency to force the laminations apart. A wiping effect, given to the contacts every time the switch is closed, keeps the contact surfaces clean and insures good contact at all times. The carbon auxiliary contacts are made of blocks of carbon fastened without screws. **In operation,** the switch is actuated by a double coil solenoid, one coil for closing and one for opening, controlled by the single pole double throw push button switch shown in fig. 2,200, which is normally in the open position and remains closed only when held by the operator. One of these switches is furnished with each control switch and must always be used, as the solenoid coils are not intended for continuous service. The power required to operate the remote control switch is small, being approximately 1.6 amperes at 110 volts, 0.81 amperes at 220 volts direct current, and 10 amperes at 110 volts, and 6 amperes at 220 volts alternating current 60 cycles. The main switch can be closed and opened by hand, and the push button located at any point.

Ques. How should double throw switches be installed?

Ans. Horizontally.



FIGS. 2,201 and 2,202.—Palmer service switch and fuse box, for either plug, cartridge or open link fuses. Fig. 2,201 illustrates the box in open position for the inspection of fuses, etc. The cover is held open by a simple lock so that the switch cannot fall closed by gravity, the box may be mounted so that the service wires lead directly into a sealed terminal chamber from any direction, and all current carrying parts made accessible by the opening of the switch are dead. Fig. 2,202 illustrates the device with side of box and cover cut away to show interior and the normally sealed cover of terminal chamber removed. The switch contacts do not enter their contact clips until the flanged cover of the box has closed the switch opening, no current connections being made to line or load until the box is completely closed, and in consequence there is no opportunity to make improper connections to any live parts of switch, when conduit connections are used to the service and meter wires.

Ques. What is a plug switch?

Ans. A switch in which the current is ruptured in a tube enclosed at one end, thereby confining the arc and limiting the supply of air.

They are used on high pressure circuits of from 10,000 to 20,000 volts, for transferring live circuits and for voltmeter and synchronizing circuits where there is very little energy. The usual current capacity is from 4 to 7½ amperes.

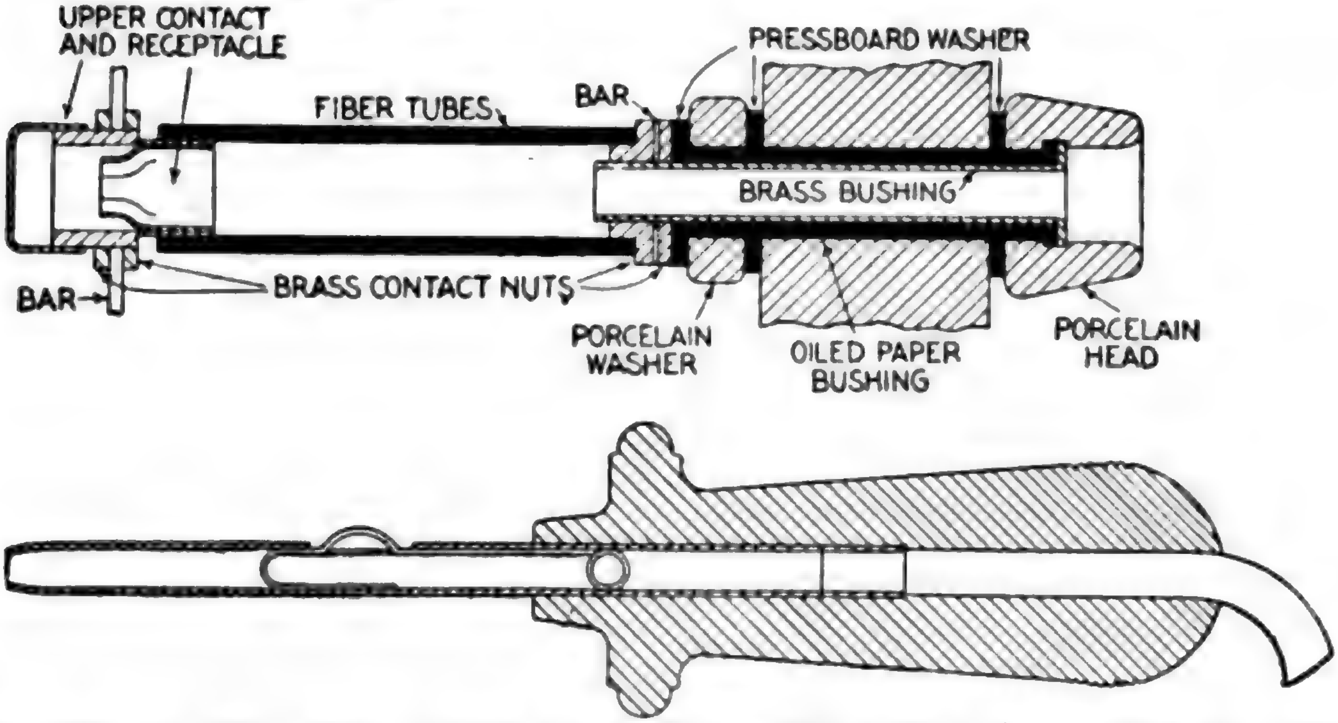

UPPER CONTACT AND RECEPTACLE
FIBER TUBES
BAR
PRESSBOARD WASHER
BRASS BUSHING
BAR
BRASS CONTACT NUTS
PORCELAIN WASHER
OILED PAPER BUSHING
PORCELAIN HEAD

FIG. 2,203 and 2,204.—**Bus transfer plug switch**. The method of supporting the contact farthest from the panel consists of a porcelain pillar of the same height as the receptacle, clamped to a brass connecting or bus bar which in turn is fastened to the receptacle.

Forms of Break.—On high pressure circuits there are several types of switch: they are classified with respect to the break, that is to say, according as the break takes place,

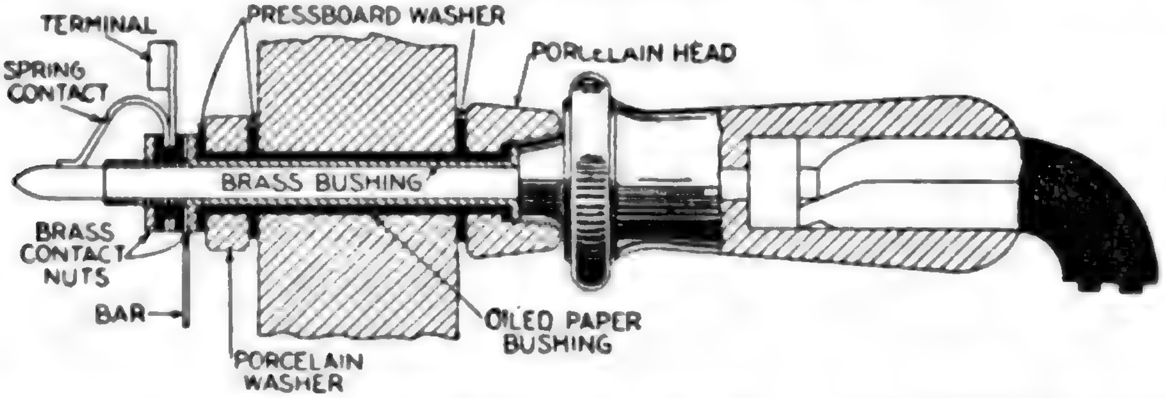

TERMINAL
PRESSBOARD WASHER
PORCELAIN HEAD
SPRING CONTACT
BRASS BUSHING
BRASS CONTACT NUTS
BAR
PORCELAIN WASHER
OILED PAPER BUSHING

FIG. 2,205.—**Ammeter jack.** This plug switch is insulated for high pressure and **consists of two parts:** *the ammeter jack, and the ammeter jack plug, cable, and bushing.* The receptacle, which is simple in construction, consists of a brass bushing well insulated from the panel and protected on the front of the panel by a porcelain bushing. **On the end of this tube** and insulated from it, is a phosphor bronze spring which, when the plug is out, rests on the brass tube and keeps the circuit closed. **The plug** consists of a brass rod well insulated and set in a brass tube, both being fastened in a handle which is stained black and polished. Inside the handle is run a twin conductor cable, one side being soldered in the brass tube and the other to the brass rod. The other end of the cable is run through a bushing set in the panel and thence to the ammeter or current transformer. Where it is desired to remove the plug and cable from the board, or to plug both ends of the cable in different receptacles, a plug instead of a bushing should be used. In this case a cable should be provided with a plug on each end.

1. In open air;
2. In an enclosed air space;
3. Aided by a metal fuse;
4. Aided by a horn;
5. In oil.

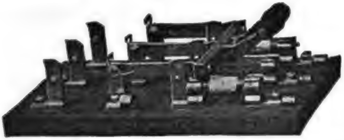


FIG. 2,206.—Westinghouse fused starting switch for squirrel cage motors. It is arranged for National Electric Code fuses on one end only and has springs on the other end to open the switch automatically if left closed at this end. The corresponding terminals at both ends of the switch are connected in grooves in the back of the slate base so that the wiring need be connected to one set of these terminals only, thus decreasing the number of connections necessary, as shown in fig. 2,207. In starting an induction motor, the switch is thrown to the end that is not fused and held there until the motor is up to running speed; then it is quickly thrown to the fused position, thus protecting the circuit under running conditions.

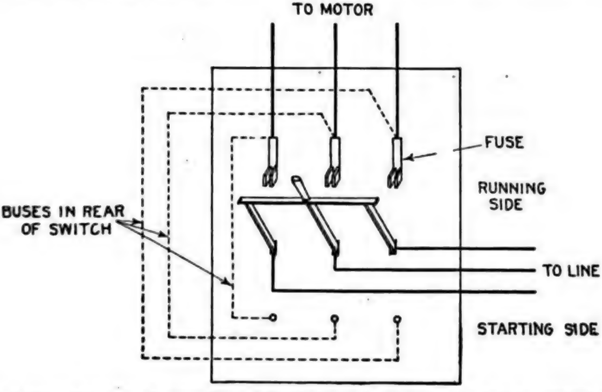


FIG. 2,207.—Diagram of connections of Westinghouse fused starting switch for squirrel cage motors. The starting current of induction motors is several times the normal running current and, when the controlling switch is fused to carry the running load only, the fuses are apt to blow when the motor is started. The fuses must be of a capacity to prevent overloads under running conditions. These switches are designed to meet this difficulty and are used without auto-starters to control motors up to 5 horse power rating.

Ques. What is the objection to open air break?

Ans. The relatively long gap required to extinguish the arc, limiting this form of switch to low or moderate pressure circuits.

The open air arc may cause very high voltage oscillations when the circuit contains inductance and capacity unless the break occur at zero value.

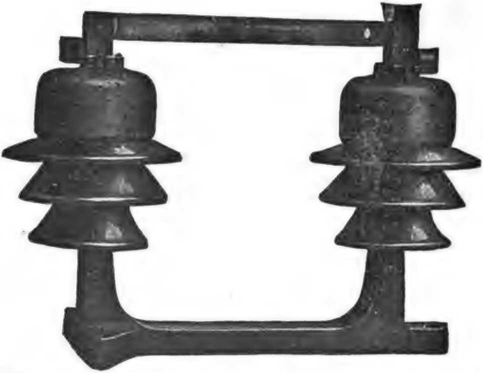


FIG. 2,208.—Westinghouse single pole disconnecting switch. Disconnecting switches are used primarily for isolating apparatus from the circuit for purposes of inspection and repair; also for sectionalizing feeders. They are not designed for opening under load, and therefore no attempt should be made to open them with current in the circuit. In connection with lightning arrester installations, disconnecting switches are particularly useful, providing a simple and effective means for isolating the arresters while cleaning and inspecting. The switch is opened and closed with a hook on the end of a wooden pole, which hook engages in a hole provided in the switch blade. This type of disconnecting switch is intended for wall mounting. The live parts are mounted on porcelain insulators carried on a cast iron yoke or base, forming a simple and substantial construction.

Ques. What are disconnecting switches?

Ans. Knife switches in series with other switches so that the apparatus controlled by the latter may be repaired in safety by entirely disconnecting it from the bus bars or live circuit.

Such switches are not intended to rupture the load current.

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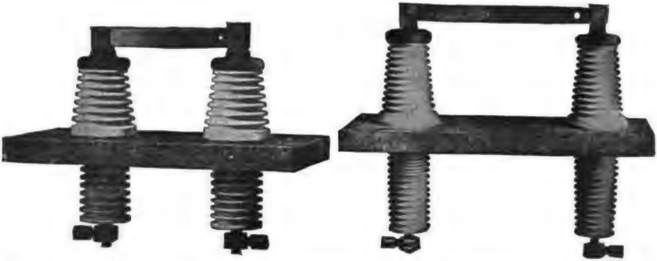
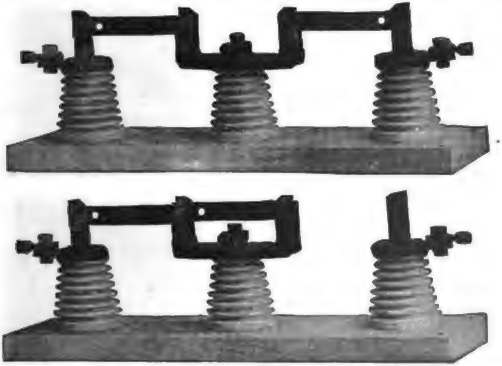


FIGS. 2,209 and 2,210.—Westinghouse disconnecting switches for pressures over 3,300 volts



FIGS. 2,211 and 2,212.—Westinghouse selector type disconnecting switch. Fig. 2,211, view showing both sides closed; fig. 2,212, view with one side open. The selector type of disconnecting switch is a transfer switch which does not require the circuit to be interrupted while making the change. It can also be used to connect two independent circuits in parallel. In construction, it is in effect two single throw, single pole disconnecting switches with the hinge jaws connected together and mounted on the same insulator. The hinge jaw is also provided with dummy jaws to hold either blade of the switch in the open position. Except for these differences in the hinge jaws, the construction is similar to the switch shown in fig. 2,209. It should not be used to open the circuit when loaded.

FIG. 2,213.—Hook stick for operating a disconnecting switch.

Ques. What are the features of the enclosed air break?

Ans. The switch is more compact than the open air break type, but pressure oscillations are caused on opening the circuit the same as with the open air break, and it is not desirable for heavy current.

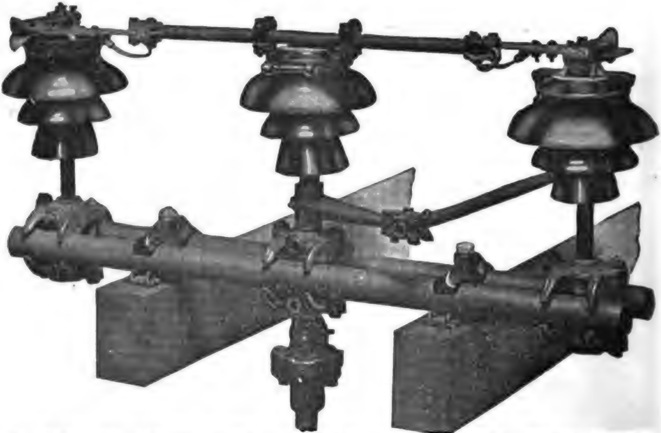


FIG. 2,214.—Baum 35,000 volt, 200 ampere, double break pole type switch. While designed for disconnecting purposes only, it can break considerable amperage. The levers and couplings are fastened with tape pins. The control shaft coupling is adjustable to any angle, and the switch can be locked in the open or closed position. A removable wooden handle is supplied and the switch can be handled in any weather. The arms can be extended to hold fuse fittings, or dead end insulators in the event of a heavy strain, but it is preferable to have fuses on another structure as a precaution against coming in contact with the energized portion of the switch, and it is also preferable to take the strain of the line on a pole a few feet from the switch, rather than on the switch structure, particularly in the larger sizes. An insulating wood section in the control shaft separates the control handle from the remainder of the switch. Discharging horns can be fitted to this type of switch and when so equipped they have been found capable of breaking considerable loads.

Ques. How is the fuse arranged in the metal fuse break type of switch?

Ans. It is placed in a tube fitted with powdered carbonate of lime or some other insulating powder.

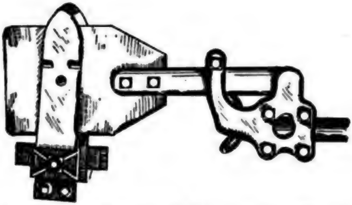


FIG. 2,215.—Pacific swivel type blade for Baum pole top switches. The **twist type** *of blade*, here shown, is especially adapted to switches operating in freezing or sleety weather. **It will be seen** that the first few degrees through which the rotating insulator is moved *have the effect of twisting the blade between the shoes of the contact*, which breaks any seal through freezing, or corrosion.

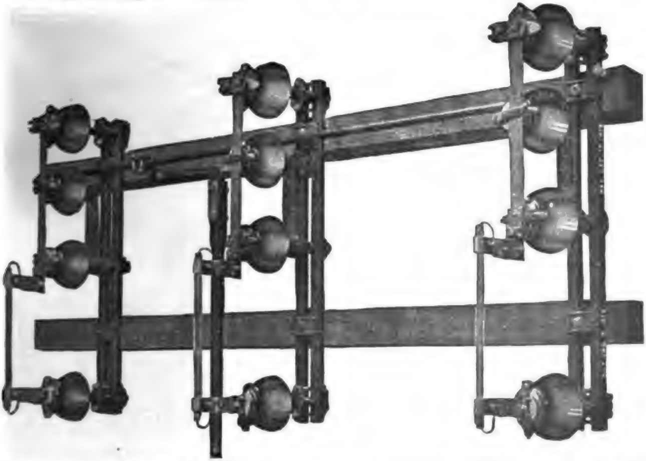


FIG. 2,216.—Pacific 22,000 volt, 100 ampere, **pole top switch** equipped with fuse tubes; designed to meet the need for a small group -controlled disconnecting switch, having several features making it suitable for use with service transformer installations and line branches. **The switch is made** with clamped pipe arms permitting adjustment. It is equipped with fuse tubes and fittings, but should the fuses be not desired, the arm may be shortened. Provision is made for fitting insulator pins to the top of the arms, when the switch is mounted vertically, which will hold insulators at right angles to the switch, making it possible to end a line on the top of these arms and then drop down through the switch to the bank of transformers. *The switch is so constructed that* **gravity** *tends to hold it in either the open or the closed position.* Provision can be made for **locking.**

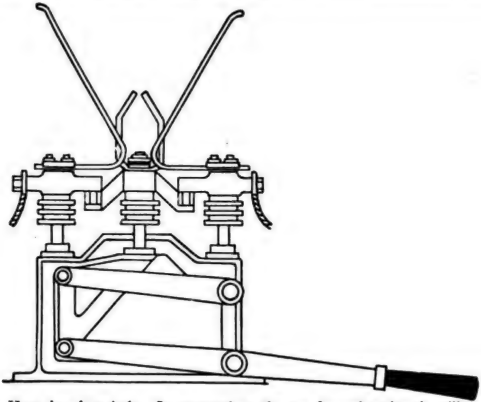


FIG. 2,217.—Horn break switch. **In operation,** the arc formed at break, will travel toward the extremities of the horns because of the fact that a circuit will tend to move so as to embrace the largest possible number of lines of force set up by it. Hence, the arc that starts between the horns where they are near together rises between them until it becomes so attenuated that it is extinguished.

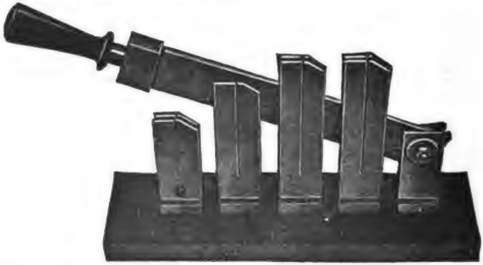


FIG. 2,218.—Westinghouse rear connected motor starting switch, for pressures up to 600 volts. It is used for starting rotary converters and direct current motors of large capacity having starting torque small enough to permit cutting out the starting resistance in few steps. The clips can be connected to any type of resistor, the steps of which are successively short circuited as the switch closes; the amount of resistance in the armature circuit is thus gradually reduced. A pause should be made after each step of resistance is thrown in to allow the motor speed to accelerate. If the starting switch do not have to carry the full load current and can be short circuited by another switch, a starting switch of smaller capacity equivalent to 50 per cent of running current of the machine can be used. The switch is of the single pole, single throw, rear connected, four point, knife blade type.

Ques. Describe its operation.

Ans. The moving arm of the switch draws the fuse through the tube, thus opening the circuit without much disturbance.

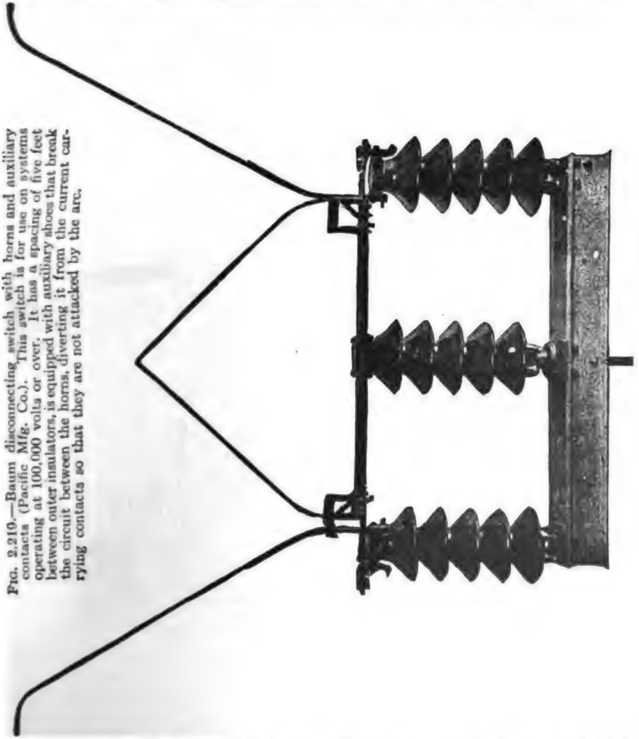


FIG. 2,210.—Baum disconnecting switch with horns and auxiliary contacts (Pacific Mfg. Co.). This switch is for use on systems operating at 100,000 volts or over. It has a spacing of five feet between outer insulators, is equipped with auxiliary shoes that break the circuit between the horns, diverting it from the current carrying contacts so that they are not attacked by the arc.

Ques. What is the objection to the metal fuse switch?

Ans. The powder is set flying by the explosion of the arc, which, as it settles, gets into the bearings of any machine that may be in the vicinity.

Ques. What is a horn break switch?

Ans. One provided with horn shaped extensions to the contacts, as shown in fig. 2,219.

The arc formed on breaking the circuit, as it travels toward the extremities of the horns, becomes attenuated and is finally ruptured.

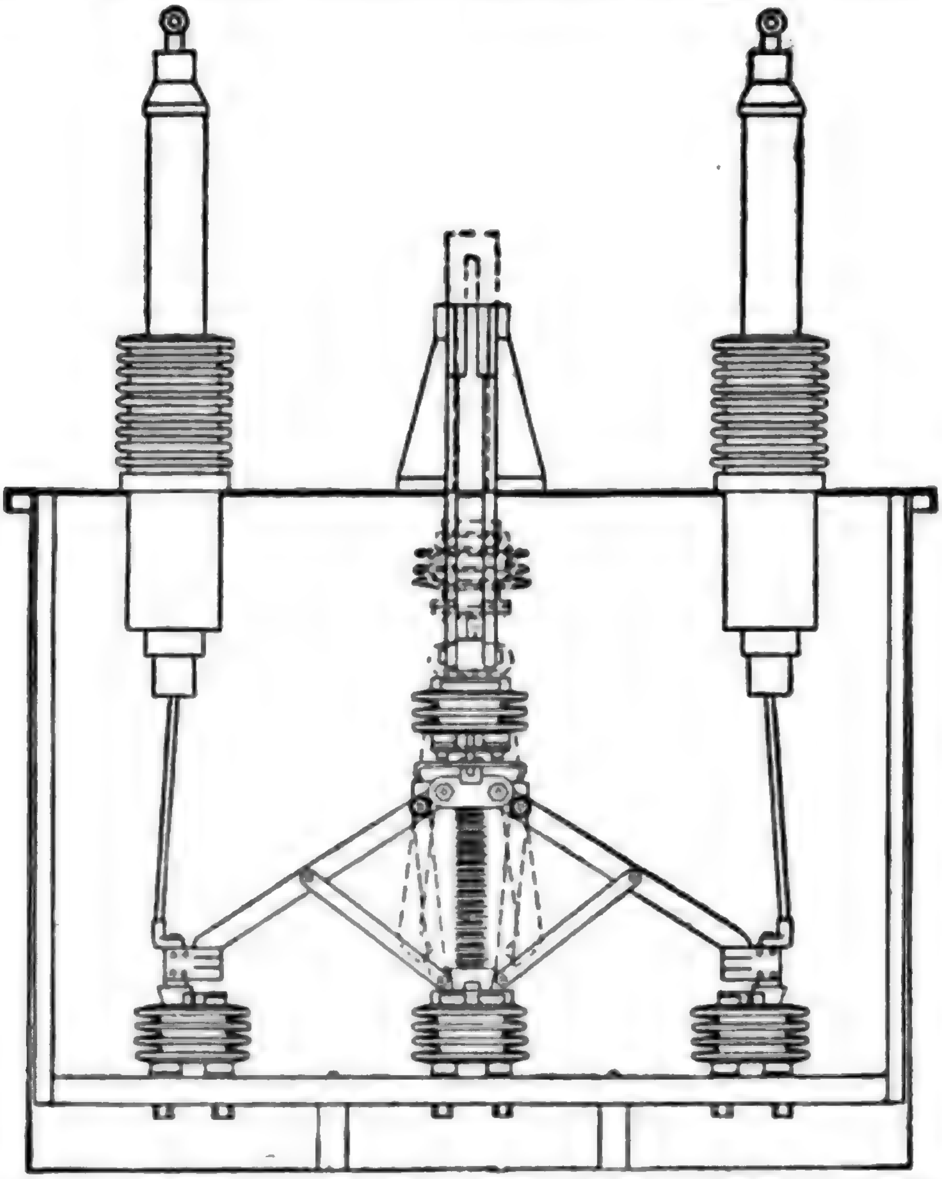


FIG. 2,220.—Kelman switching mechanism. The pantograph arrangement of the contact blades gives a double horizontal break deep down in the oil. This gives over the break a heavy head of oil which immediately closes in around the thin blades as they leave the contacts in opening, thus effectually extinguishing the arc. The opening spring acts within the pantograph itself without any intervening mechanism, and the light weight of the few moving parts enables the spring to accelerate the blades rapidly, thus obtaining a quick break. The contacts are of the return bend type, which makes a flexible contact, to obtain alignment with the blades at all times. The pantograph and contacts are supported on corrugated porcelain insulators on a hardwood base or insulator board. The insulators are fitted with iron ends for securing the different parts. At each end of the insulator board is an upright or lifting board which serves to lift the switching mechanism out of the tank. The leads are heavily insulated.

Ques. What are the objections to this type of switch?

Ans. The considerable space required for the horns and arcs, and the line surges caused by the arc.

Horn switches were used extensively for high pressure alternating current circuits before the introduction of oil switches.

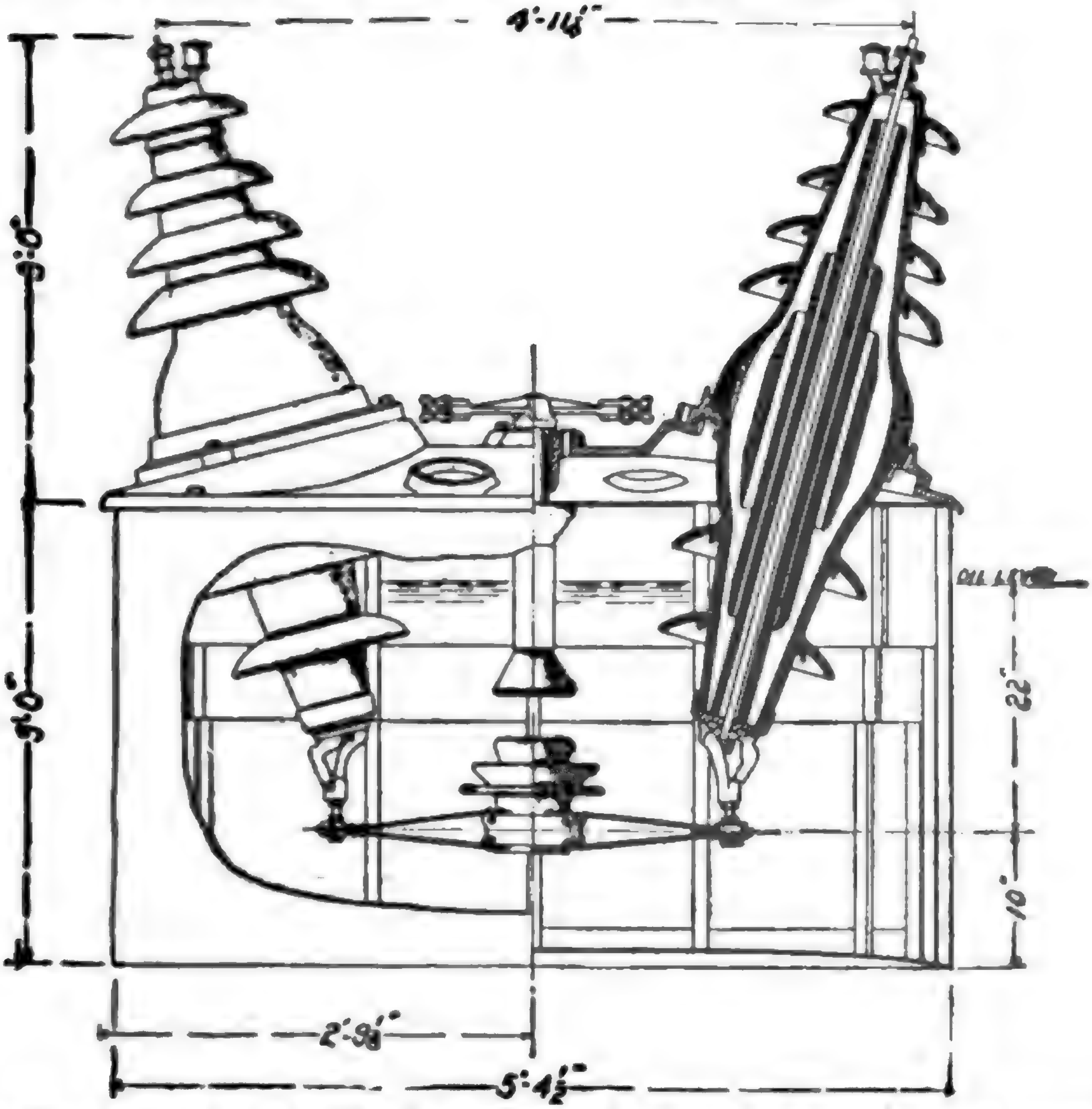


FIG. 2,221.—Sectional view of Pacific weatherproof oil switch for use in places exposed to the weather. All moving and contact parts are supported from the cast iron top and are readily removable for inspection or repair

Oil Switches.—The extensive use of high pressure currents and alternating current motors and other devices introducing inductance make it necessary to use switches radically different from the ordinary air break types.

The opening of circuits of considerable current value with inductive loads is not possible with old style switches which

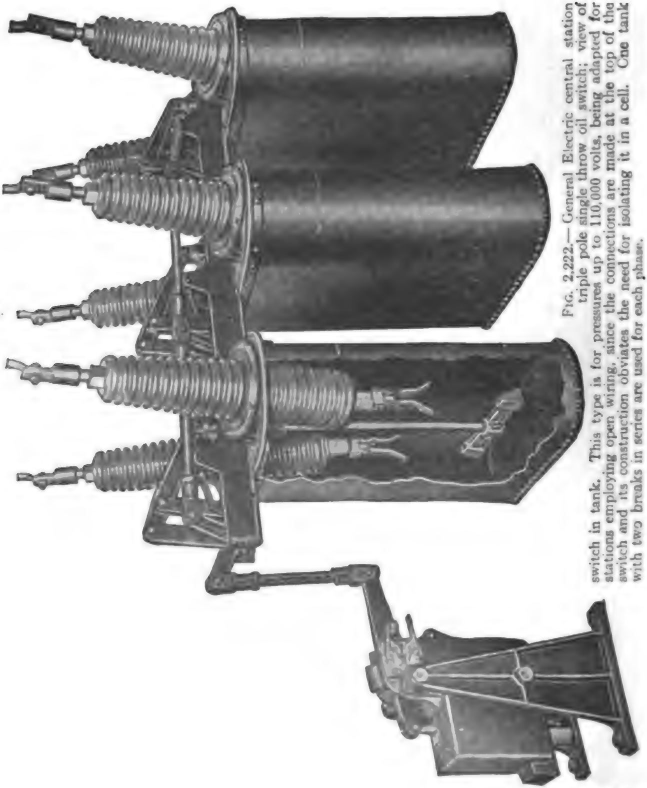
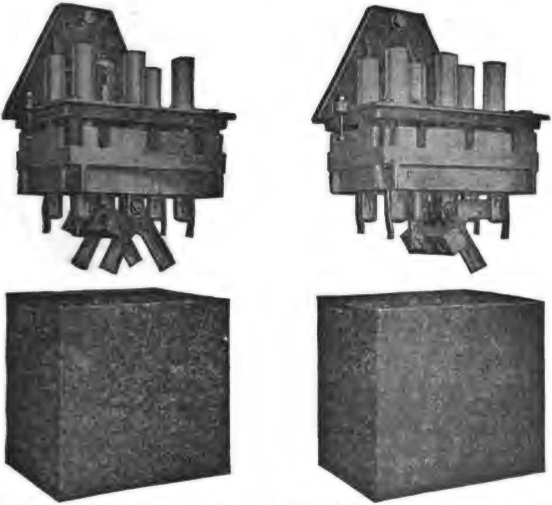


FIG. 2,222.—General Electric central station triple pole single throw oil switch; view of switch in tank. This type is for pressures up to 110,000 volts, being adapted for stations employing open wiring, since the connections are made at the top of the switch and its construction obviates the need for isolating it in a cell. One tank with two breaks in series are used for each phase.

were quite adequate for the service for which they were designed. These circuits are controlled with ease and certainty by the oil switch.



FIGS. 2,223 to 2,226.—Westinghouse indoor, two pole double throw oil switch for pressures not over 6,600 volts. Fig. 2,223, open position; fig. 2,225, closed position. This type of switch is suited for a wide range of application, being made in both switchboard and wall mounting styles; also for remote mechanical control by the use of bell cranks and connecting rods. The wall mounting style is adaptable to motor installations on account of the facility with which it may be mounted on any support, convenient to the motor operator. The lever and handle extend outward over the oil tank, so that the switch may readily be mounted against a wall, post or any vertical support. The characteristic features of this type of switch are: knife blade contacts submerged in oil; live parts carried on a porcelain base affording a permanent insulation between adjacent poles, and between the frame and live parts; compactness and accessibility; enclosure of all live metal parts; and low first cost. Each contact jaw has attached to it an arcing piece which takes the final break, thus preventing any burning of the jaws. These arcing pieces are inexpensive and readily replaced when worn or burnt away. The contact making parts are enclosed in a sheet metal oil tank which has an insulating lining. The leads are brought out at the top. Connections to the outside circuit are made inside the switch and a porcelain insulator is slipped over the joint, thus providing a straight continuous connection from the line with maximum insulation. On the 6,600 volt switch, insulation is obtained by the use of porcelain bases for supporting the live parts. In the 3,300 volt switch specially treated wooden bases are used, suitable barriers being provided between the poles where necessary to prevent arcs communicating.

Ques. What is an oil switch?

Ans. One in which the contact is broken under oil.

This type of switch is the one almost universally used on high pressure alternating current circuits, because of the fact that the oil tends to cause the current to break when at its zero value, thus preventing the heavy arcing which would occur with an air break switch, and the consequent surges in the line which are so often the cause of breakdown of the insulation of the system.

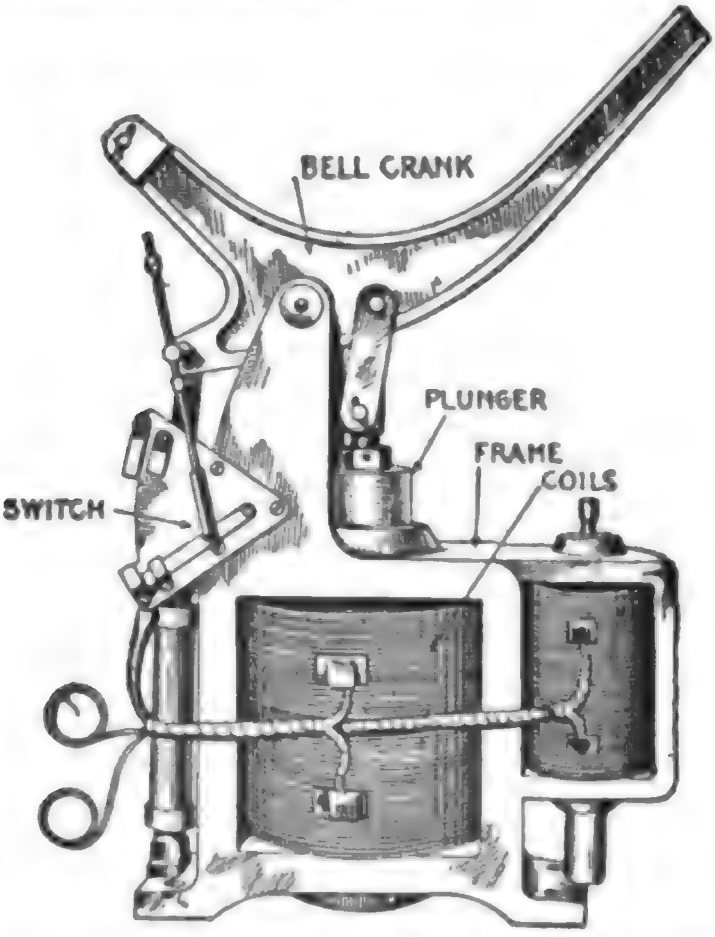


FIG. 2,227.—Kelman electric control unit for oil switch. It consists of an iron frame which contains the opening and closing coils and the bearings for the operating bell crank. A small switch on the frame automatically opens the coil circuit at the end of the stroke in either direction and operates signal lamps to indicate the open or closed position. The automatic overload release opens the switch by closing the opening coil circuit. This electrical operating unit gives satisfactory service through a wide variation of voltage. It requires a momentary expenditure of energy of from 1,500 to 4,000 watts, depending on the size.

Ques. What is the nature of an oil break?

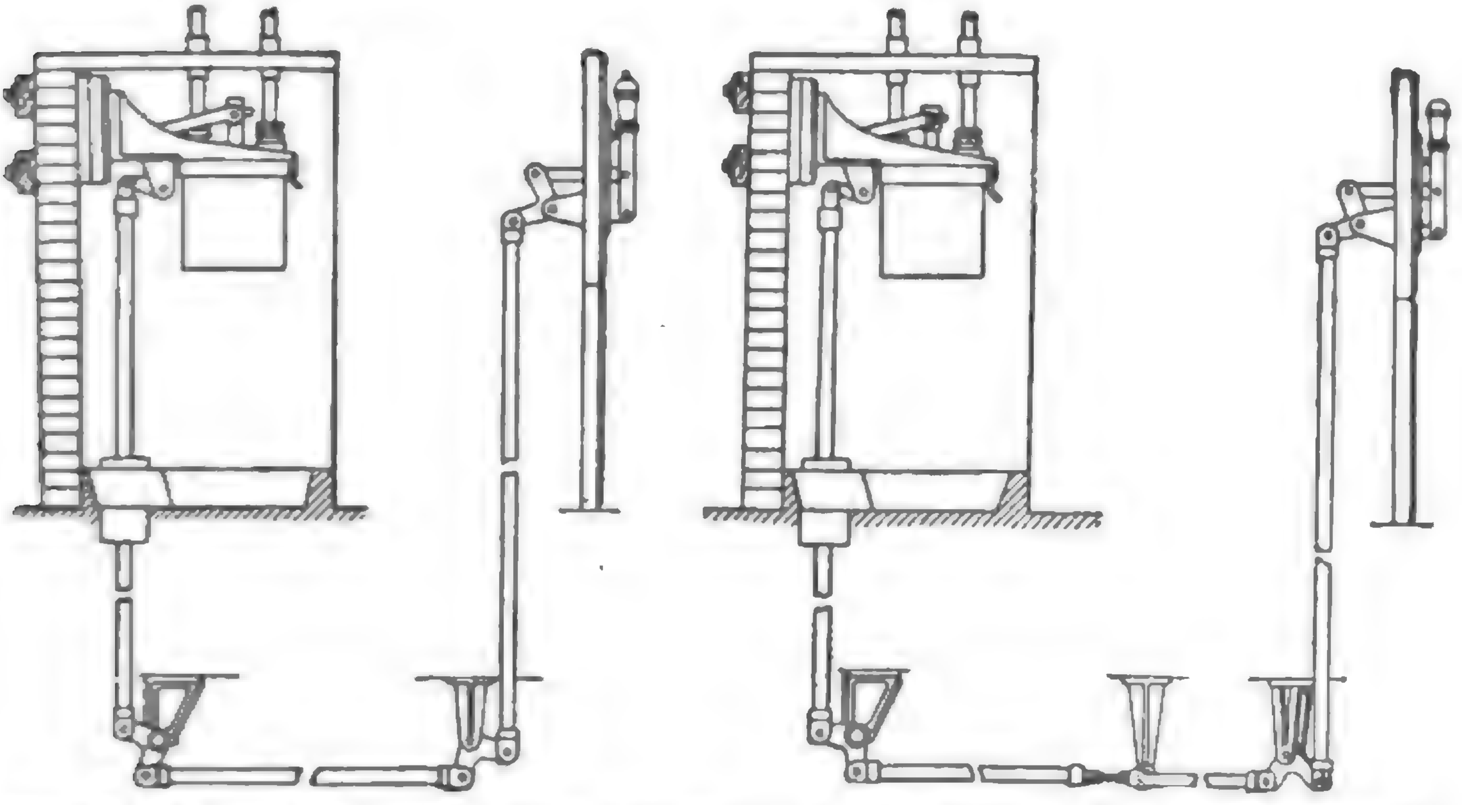
Ans. It is not a quick break.

Oscillograph records show that the effect of the oil is to allow the arc to continue during several cycles and then to break the current, usually at the zero point of the wave

Remote Control Oil Switches.—It is desirable in the case of switches on high pressure circuits to locate the parts which carry the high pressure current at some distance from the switchboard in order that they may be operated with safety.

With respect to the manner in which the switches are operated they may be classed, as

1. Hand operated;
2. Power operated.



FIGS. 2,228 and 2,229.—Views showing mechanism of hand operated remote control switches. Fig. 2,228, straight mechanism; fig. 2,229, angular mechanism.

Ques. What kind of power is used?

Ans. Electricity is used in most cases; in some installations, switches are operated by compressed air.

Ques. For what pressures should remote control switches be used?

Ans. For pressures above 1,100 volts.

Ques. Describe the operating mechanism of a remote control, hand, and electrically operated switch.

Ans. For hand operation, the mechanism between the operating lever and switch proper, consists simply of a system of links and bell cranks. Various shapes of bell crank are used, to permit change in direction or position of the force applied to operate the switch.

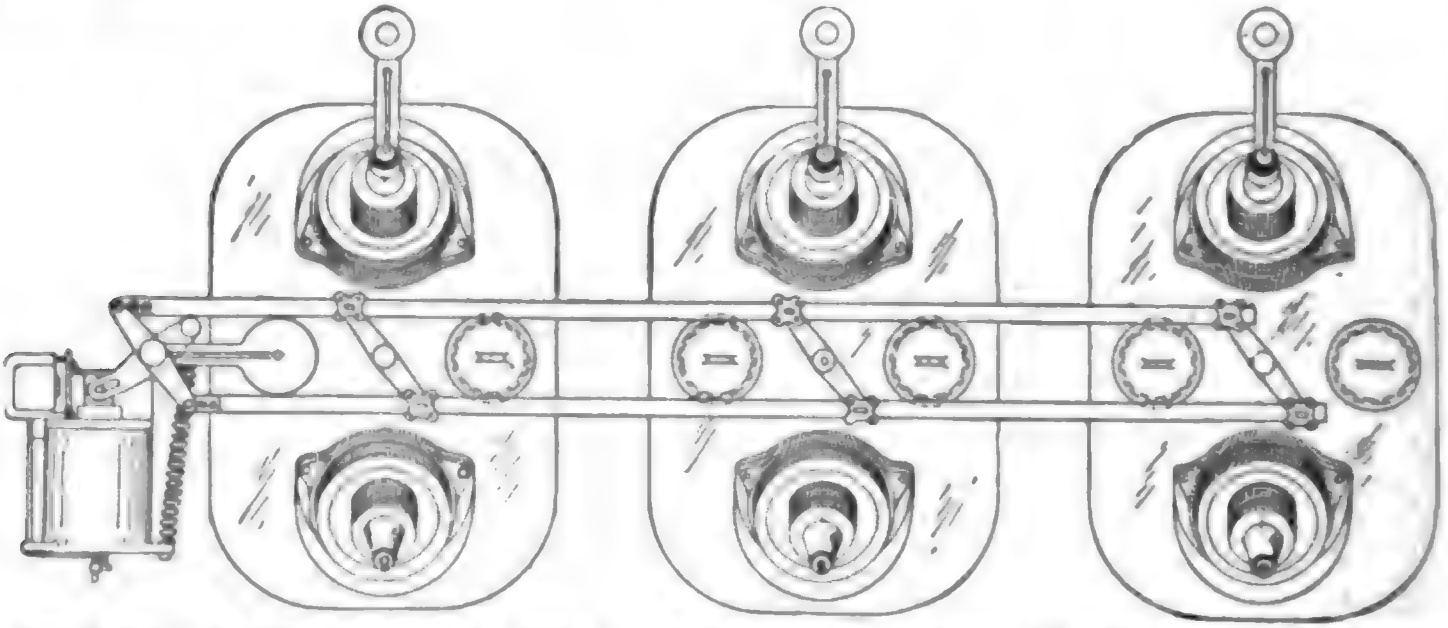


FIG. 2,230.—Pacific **oil switch with solenoid control**, designed for 60,000 and 70,000 volt installations; it is capable of handling a 25,000 kw. generating station. The break is horizontal, made by the rotation of a flat member edgewise through the oil. The solenoid, at its extreme outer position, has a free start before commencing to move the control parts of the switch. As it approaches the extreme inner position, where the opening spring and the contacts begin to offer the greatest resistance, the magnetic action is, of course, most powerful, and the leverage by which it is applied moves to an increasing radius, by means of rollers working in the curved slots of the control shaft levers. These curved slots and rollers have the additional advantage of making the opening action very free and smooth. The tripping coil does not act on the latch directly, but gives a hammer blow that is positive. The latch proper is a roller having a powerful hold and easy release. Current can not be left on either the closing or opening coils, as they are automatically cut out by the movement of the switch.

Ques. Name two classes of electrically operated remote control switch.

Ans. Those operated by solenoids, and those operated by motors.

The solenoid type are closed by the action of a plunger solenoid, and opened either by another solenoid called a "tripping coil" or by gravity. Some examples of remote control are shown in the accompanying illustrations.

Ques. What indicating devices are used with electrically operated switches?

Ans. Red and green lamps; **red** for *closed* and **green** for *open* as shown in fig. 2,231.

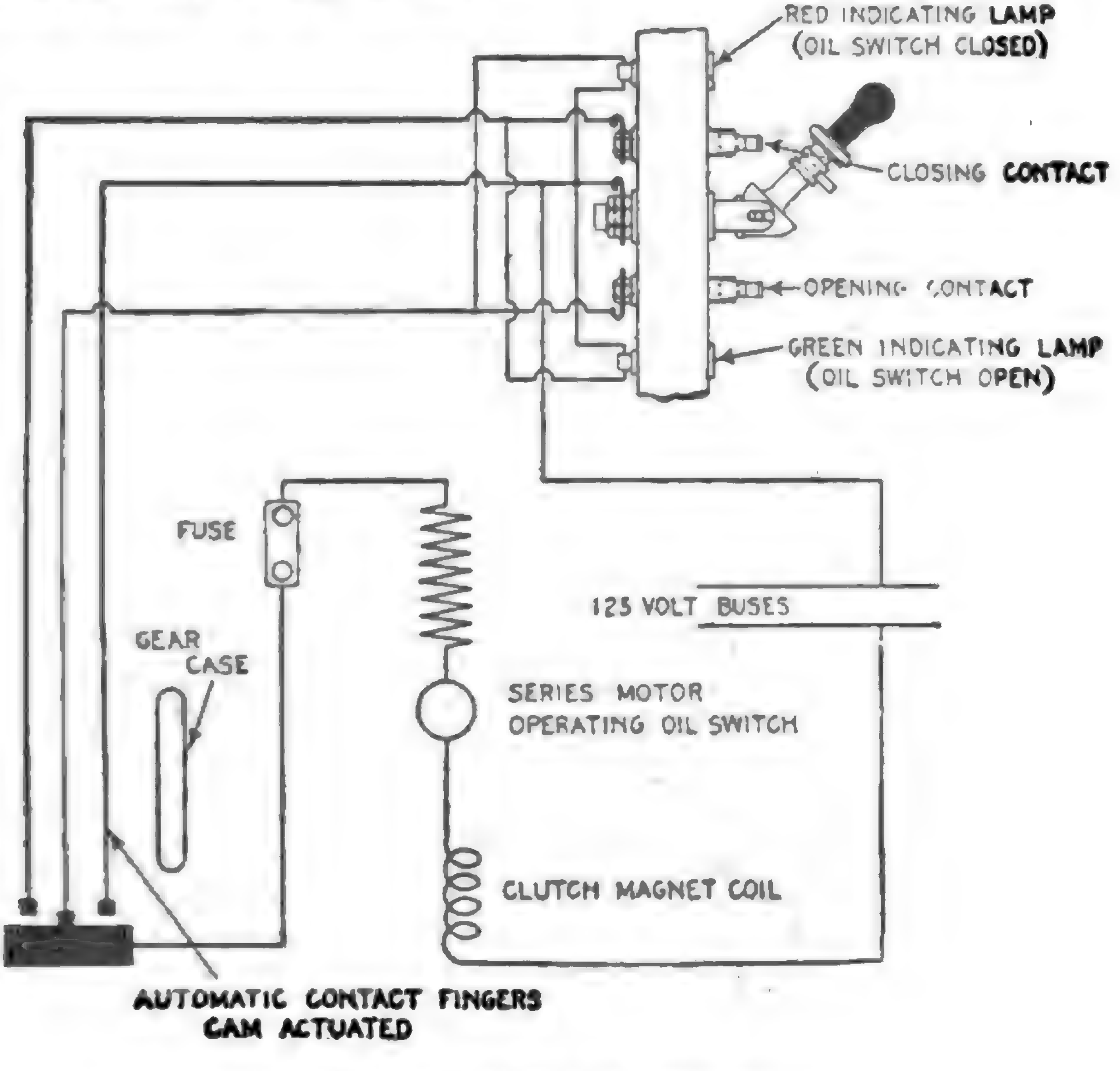

RED INDICATING LAMP (OIL SWITCH CLOSED)
CLOSING CONTACT
OPENING CONTACT
GREEN INDICATING LAMP (OIL SWITCH OPEN)
FUSE
125 VOLT BUSES
GEAR CASE
SERIES MOTOR OPERATING OIL SWITCH
CLUTCH MAGNET COIL
AUTOMATIC CONTACT FINGERS CAM ACTUATED
OIL SWITCH IN CLOSED POSITION

FIG. 2,231.—Diagram of connections of motor operated remote control switch. The motor which operates the switch is controlled by a small lever generally mounted on the panel with the instruments which are in the circuit controlled by the switch. The standard pressure for operating the motors is 125 volts.

Ques. For what service are motor operated switches used?

Ans. For exceptionally heavy work where the kilowatt rupturing capacity is greater than that for which the other types are suitable.

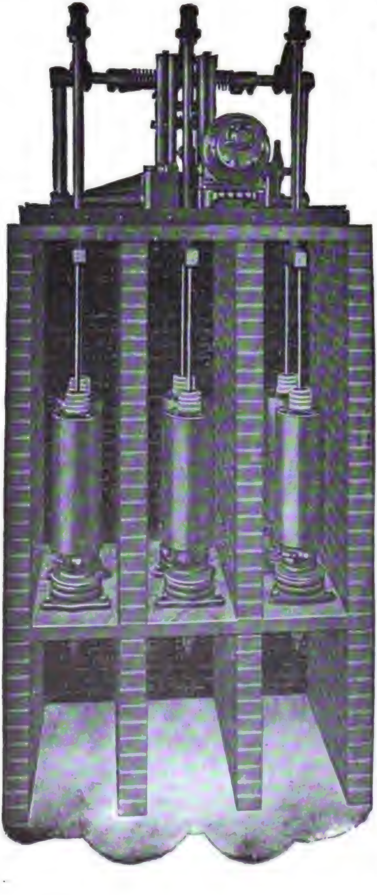
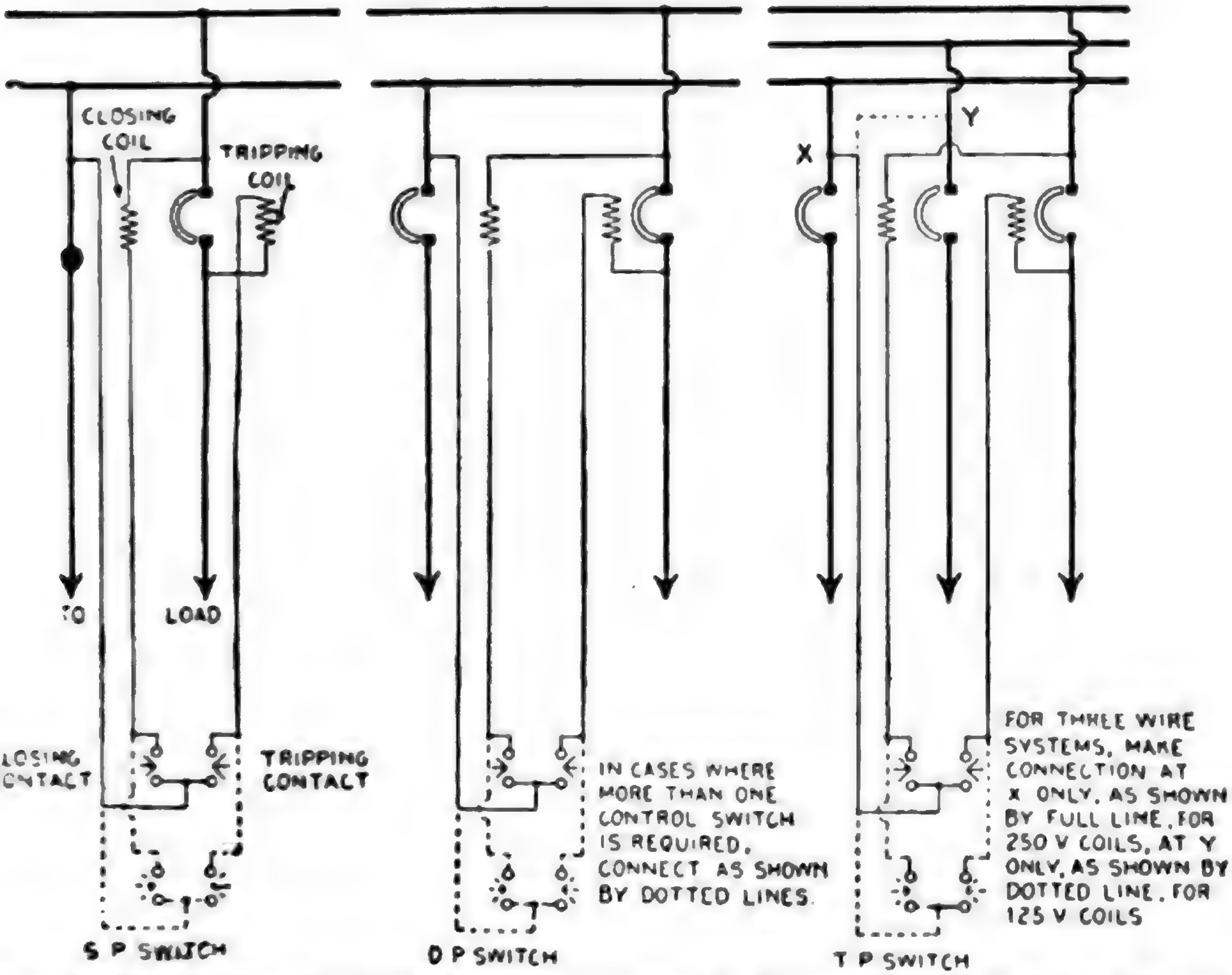


Fig. 2,232.—General Electric motor operated three phase oil switch. The operation of the oil switch is accomplished by a small hand controlling switch, generally mounted on the panel, with the instruments which are in the circuit controlled by the oil switch. The standard pressure for the operating motor is 125 volts. The switch has six breaks, each break being in a separate tank. In addition to this isolation of the breaks, each phase is enclosed in a fireproof brick compartment, making it impossible for trouble in one phase to be communicated to another. The cells are constructed of brick with top and bottom slabs of slate. The capacities of such switches, range from 2,500 to 60,000 volts, and from 100 to 1,000 amperes.

Rupturing Capacity of Oil Switches.—While an oil switch may be designed for a given pressure and to carry a definite amount of current, it should not be understood that the switch will necessarily rupture the amount of normal energy equivalent to its volt ampere rating.



IN CASES WHERE MORE THAN ONE CONTROL SWITCH IS REQUIRED, CONNECT AS SHOWN BY DOTTED LINES.

FOR THREE WIRE SYSTEMS, MAKE CONNECTION AT X ONLY, AS SHOWN BY FULL LINE, FOR 250 V COILS, AT Y ONLY, AS SHOWN BY DOTTED LINE, FOR 125 V COILS

FIGS. 2,233 to 2,235.—Diagrams showing connections for General Electric single, double, and triple pole, solenoid operated remote control switches. The operating coils are shown connected to main switch circuit, but may be connected to an entirely separate control circuit. Connections are the same for either alternating or direct current.

Oil switches are often used on systems with generator capacity of many thousand kilowatts. It is therefore essential that the switches shall be able to break not only their normal current, but also greatly increased current that would flow if a short circuit or partial short circuit occur.

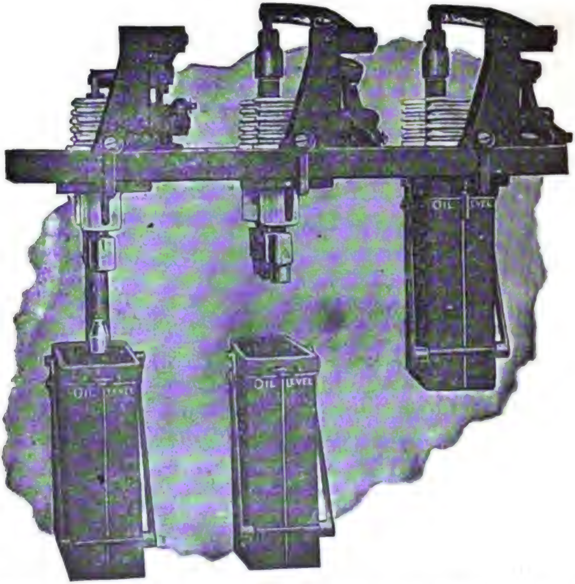


FIG. 2,236.—Westinghouse three pole hand operated remote control oil switch, adapted for the control of alternating current circuits of small and moderate capacities, the pressures of which do not exceed 25,000 volts. Each unit is installed in a separate masonry compartment. The open position of contacts is maintained by gravity. Up to and including the 600 ampere capacity, the contacts are cone shaped with an arcing tip. as shown for capacities in excess of 600 amperes, brush contacts are furnished with auxiliary arcing contacts of the butt type. Each pole has two sets of contacts, thus providing a double break in each line. With both types of contact, the final break of the arc is taken and the main contacts protected by auxiliary arcing contacts which are inexpensive and readily renewable. The upper or stationary contacts are mounted on porcelain insulators secured in the soapstone base. The lower or movable contacts are carried by a wooden rod connected to and moved vertically by the operating mechanism. The operating mechanism of the hand operated breaker consists of a simple system of levers, bell cranks, and rods. The necessary energy for making a positive contact is small owing to the use of a toggle mechanism. The leads are brought out of the top of the breaker through heavy porcelain insulators. On breakers above 3,500 volts, the connections to the line wires are made by means of a union which can be tightened with a socket wrench fitting inside the insulator. As the leads coming into the switch are necessarily insulated wire or cable, this arrangement eliminates all exposed live parts and is well adapted to making connections readily to bus bars located above or in the rear of the circuit breakers.

Under short circuit conditions alternators develop instantaneously many times their normal load current, while the sustained short circuit current is approximately two and a half to three times normal, or even higher with turbine alternators.

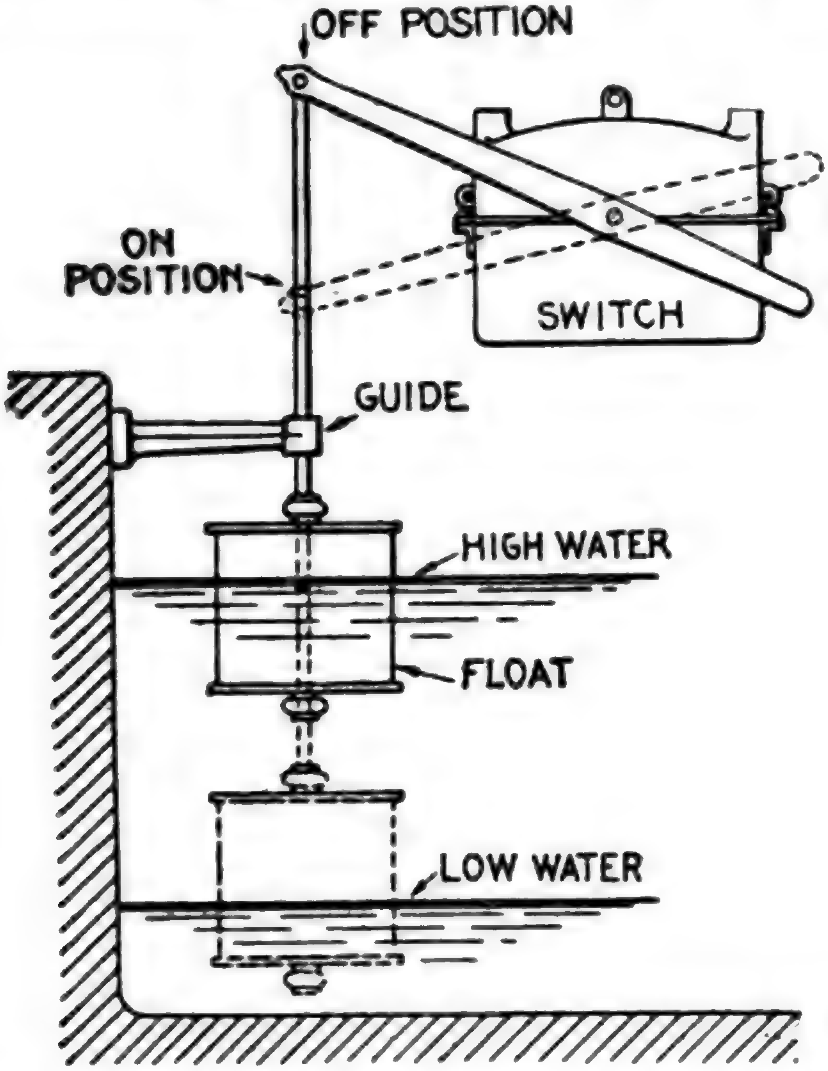


FIG. 2,237.—Cutler Hammer **enclosed float switch,** designed for the automatic control of alternating current motors operating pumps used to fill or empty tanks, sumps or other reservoirs. **The switch is operated** *by the rise and fall of a copper float which is connected to the switch lever by a brass rod or copper chain.* As the water level rises and falls, the float moves up and down. This movement is transmitted to the switch lever and the switch (if the movement be sufficient) is tripped to make or break the motor circuit. **To insure the best operation** it is necessary that the float rod be provided with a guide so that the float will move up or down in a vertical line, as shown. The minimum difference in water level at which the switch will operate is approximately 10 to 12 inches. When the float is placed in a closed tank, the minimum height inside from the bottom of the tank to the top should be at least 6 inches greater than the difference in water level to provide sufficient clearance for the float. **When this type switch is used as a tank switch,** the contacts are closed when the water level is low, putting the motor, driving the pump, in motion. When the water in the tank reaches a predetermined high level the float arm opens the switch contacts, and the motor is disconnected from the line. **For sump pump purposes,** the contacts open on low level and close on high level, the lever being reversed for this purpose. Two pole, three pole and four pole switches of this type are made, all arranged to completely disconnect single phase, two phase and three phase motors from their circuits. When used with small motors which may be thrown across the line to start, the switch may be used without a self starter if desired.

Hence, circuit breakers of the so called instantaneous type must be capable of rupturing the circuit when the current is at a maximum, whereas, non-automatic switches, or circuit breakers with time limit relays will be required to interrupt only the sustained short current circuit. The reason is evident, since the delay in opening the switch allows the current to approach the sustained short circuit conditions.

CHAPTER LVIII

CURRENT AND PRESSURE LIMITING DEVICES

In any electric installation there must be provided a number of automatic devices to secure proper control. The great multiplicity of devices designed for this purpose may be divided into two general classes, as

1. Current limiting;
2. Pressure limiting.

Because of the heating effect of the current which increases in proportion to the square of the strength of the current, it is necessary to protect circuits with devices which do not allow the current to exceed a predetermined value.

Accordingly fuses, circuit breakers, reactances, etc., are used, each possessing certain characteristics, which render it suitable for particular conditions of service.

For instance, just as in analogy, steam boilers must be protected against abnormal pressures by safety valves, electric circuits must be guarded against excessive voltages by pressure limiting devices, otherwise much damage would occur, such as the burning out of incandescent lamps, grounding of cables, etc.

The control of steam is simple as compared to the electric current, the latter being the more difficult to manage because of its peculiar behaviour in certain respects, especially in the case of alternating current which necessitates numerous devices of more or less delicate construction for safety both to the apparatus and the operator.

Fuses.—A fuse is "an electrical safety valve", or more specifically, *the actual wire or strip of metal in a cut out, which may be fused by an excessive current*, that is to say, by a current which exceeds a predetermined value. A fuse, thus serves to protect a circuit from any harm resulting from an undue overload.

Fuses have been treated at such length in Guide No. 2, Chapter XXV, that very little can be said here, without repetition.

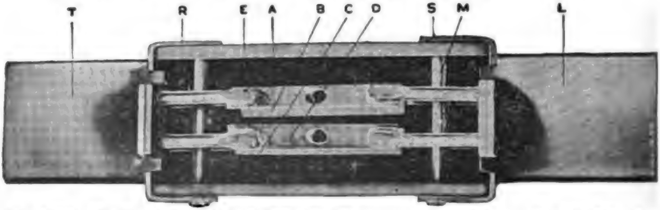


FIG. 2,238.—Sectional view of Noark 250 volt, 400 ampere **enclosed fuse. The fusible element** *is divided into strips* A, B, C, and D. This parallel link construction results, upon the operation of the fuse, in the formation of a number of small arcs, thus facilitating the absorption of the metal vapor formed when the fuse blows. **The fusible strips,** of which there are two or four in number, according to the ampere capacity of the fuse, are entirely surrounded by a granular material which is chemically inactive with respect to the fusible link and whose function is to absorb the metallic vapor formed upon the blowing of the fuse. **The contact blades** T and L are made of round edge copper, the round edges facilitating the insertion of the fuses in the circuit terminals. R and S are the end ferrules, attached to cover E, by the pin M.

Ques. What effect have the terminals on a fuse?

Ans. The current at which a fuse melts may be greatly changed by the size and shape of the terminals.

If near together and large, they may conduct considerable heat from the fuse thus increasing the current required to blow the fuse.

Ques. What is the objection to large fuses?

Ans. The discharge of molten metal when the fuse blows is a source of danger.

Ques. What should be used in place of large fuses?

Ans. Circuit breakers.

Ques. What are the objections to fuses in general?

Ans. The uncertainty as to the current required to blow them; the constant expansion and contraction is liable to loosen the terminal screws when screws are used.

Ques. What is the advantage of fuses?

Ans. They form an inexpensive means of protecting small circuits.

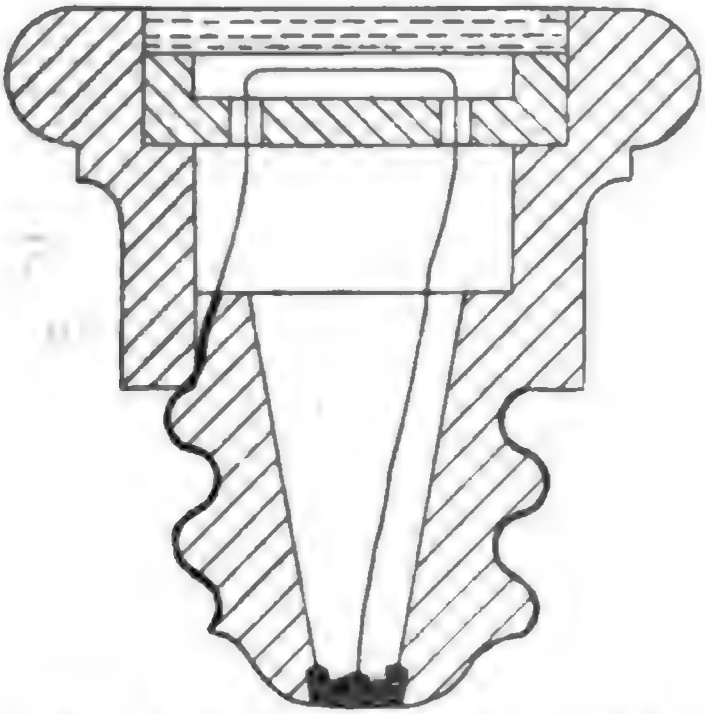


Fig. 2,239.—Cross section through plug fuse. With this type of fuse it is impossible to place any except the correct size of plug in the socket.

Ques. Describe a plug fuse.

Ans. It is constructed as shown in fig. 2,239, the fuse wire being visible and stretching between the two metal portions of the plug.

Ques. What is a cut out fuse?

Ans. One similar to a simple fuse, but provided with clip contacts as used for knife switch contacts.

The fuse wire is usually contained in a china or porcelain tube, which also serves the purpose of a handle for withdrawing the fuse.

Ques. What is an expulsion fuse?

Ans. One in which the fuse is placed in an enclosed chamber with a vent hole.

In operation, when the fuse blows, the hot air and molten metal are expelled through the vent.

Ques. What is a no arc fuse?

Ans. A cartridge type fuse, in which the space surrounding the fuse wire is filled with powdered material.

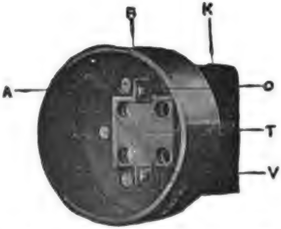


FIG. 2,240.—Inside view of end ferrule of Noark enclosed fuse. Two prongs O and V, which are a part of the knife blade K, pass through the square holes in the ends of the ferrule K, and are riveted to the anchor plate T. **The object of this plate** *is to stiffen the structure and to increase the current carrying capacity of the metal between the holes, also to permit of proper alignment of the plates.* In each ferrule is placed a **vent screen,** composed of reticulate material, such as cheese cloth. The fuzz between the threads ot the cheese cloth prevents the escape of the granular material through the vent holes A, but when the fuse operates, allows free egress of the air, thereby permitting the vapor formed upon the operation of the fusible element to quickly and freely pass through the interstices of the filling material and become cooled, eliminating any possibility of flame issuing from the ends of the tube.

The object of the powdered material is to assist in extinguishing the arc formed when the fuse blows.

Ques. What is a magnetic blow out fuse?

Ans. An enclosed fuse which is subject to the action of a magnetic field produced by the current, the magnetic field tending to blow out the arc when fusing occurs.

Ques. What is a quick break fuse?

Ans. One having a weight suspended from its center, or springs attached to its ends so that the arc formed at fusing is quickly attenuated and extinguished.

Ques. What is the disadvantage of a fuse as compared to an oil switch circuit breaker?

Ans. When a fuse blows, the arc causes oscillations in the line, which cause excessive rise of pressure under certain capacity conditions, whereas this disturbance is reduced to a minimum with an oil switch.

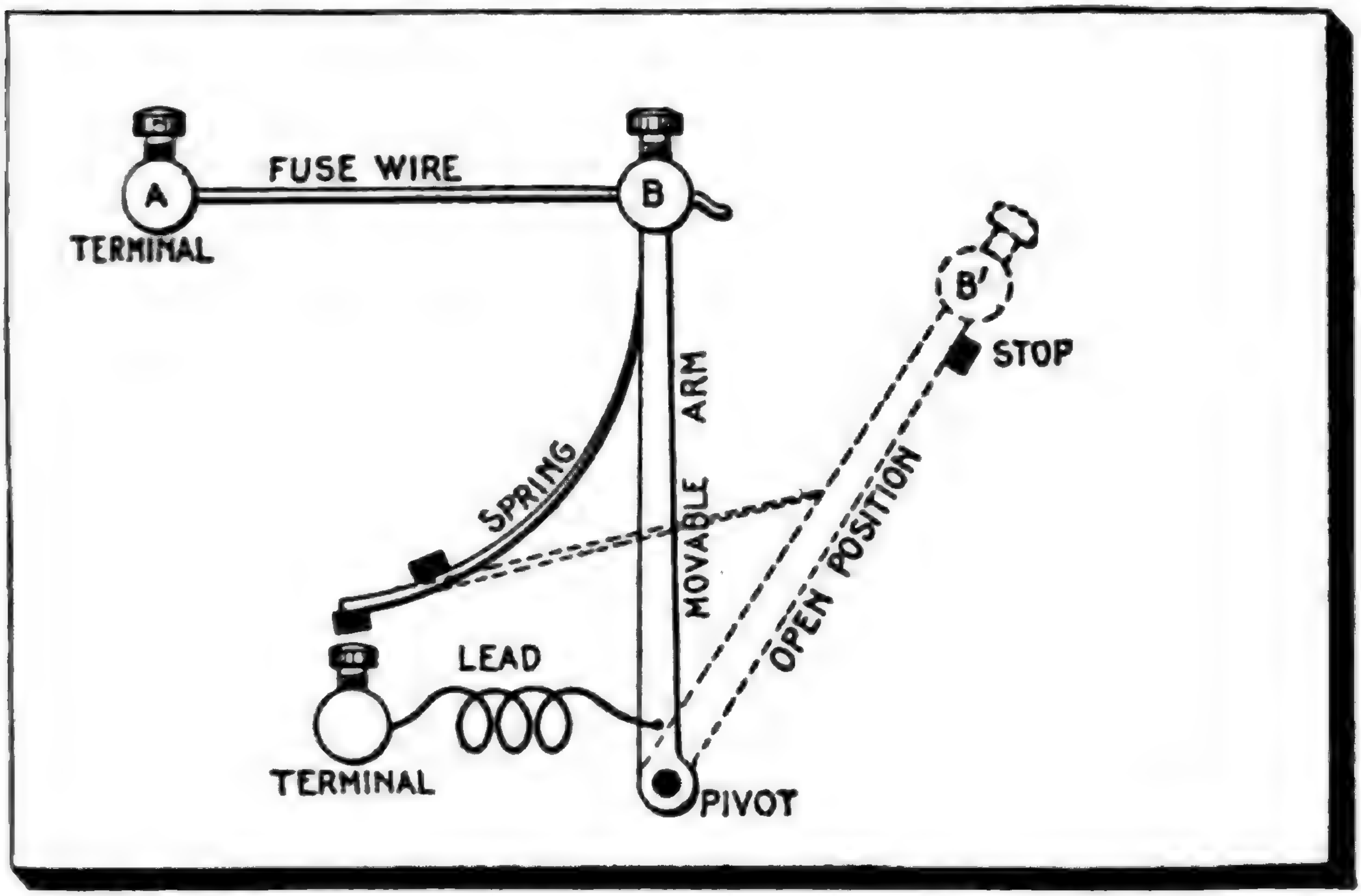


FIG. 2,241.—**Quick break fuse.** The fuse wire is connected between the fixed terminal A and the movable arm B, and is held under tension by the spring which exerts pressure on the movable arm in a direction tending to separate A and B. **In operation**, when the fuse blows, the movable arm quickly moves to the position B′, thus attenuating the arc and accelerating its extinguishment.

Ques. What metal is used for fuse wires?

Ans. Various metals. Ordinary fuse wire is made of lead or an alloy of lead and tin.

Ques. What is the objection to aluminum?

Ans. It becomes coated with oxide or sulphide, which acts as a tube tending to retain the metal inside and prevent rupture.

Ques. What is the objection to copper?

Ans. Its high fusing point.

Current Limiting Inductances.—The great increase in capacity of power stations, for supplying the demands of densely populated centers and large manufacturing districts, together with the decrease in the reactance of modern alternators and transformers due to improvement in design to obtain better regulation, has presented a problem in apparatus protection not contemplated in the earlier days of alternating current distribution. This problem is entirely separate and distinct from that of eliminating the tendency toward short circuit, incident to the high voltages now common in transmission lines. It accepts that all short circuits must occasionally occur and considers only the protection of the connected apparatus against the mechanical forces due to the magnetic stresses of such enormous currents.

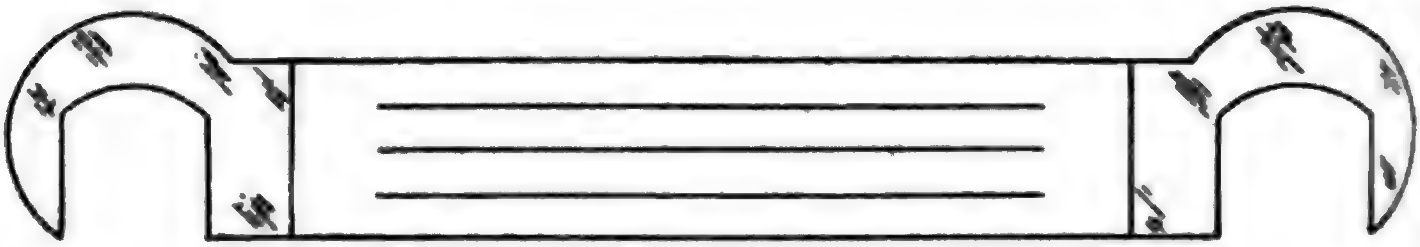


FIG. 2,242.—**Notched end fuse.** This is a simple form of fuse **consisting of** *a strip of metal (or wire) fixed between two end pieces to fit around the terminals.* This type is often proportioned so that it is only possible to place the correct size of fuse in the terminals. Sometimes, in place of the end pieces as shown, the fuse metal is fixed between two clamping screws.

Ques. What means are employed to limit the value of a short circuit current?

Ans. A current limiting inductance coil (called a *reactance*) is placed in series with the alternators or transformers.

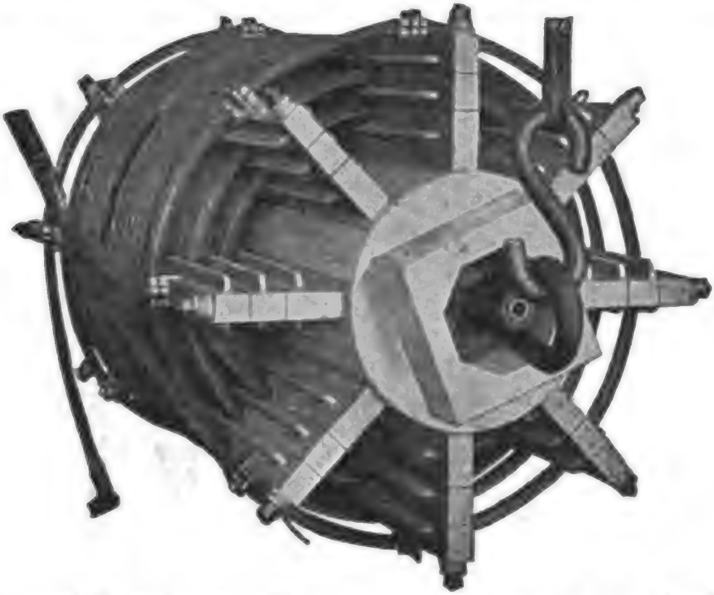


FIG. 2,243.—General Electric current limiting reactance; view showing details of construction. The core consists of a hollow concrete cylinder, alloy anchor plates or sockets being embedded in the core near the ends to receive the radial brass bolts. An extension at each end of the core provides for clamping and bracing the reactance in installation. The supports for the winding are made of resin treated maple and are located upon the core by radial brass studs screwed into the alloy sockets, and insulated by mica tubes. The nuts by which the structure is tightened, rest upon heavy fibre washers. Wooden barriers fitted and shellaced into the supports add to the creepage surface between layers of the winding and between the winding and the core. The supports of the layer next to the core are separated from the core by strips of treated pressboard. The coil consists of bare stranded cable in several layers, usually three in number. It is wound into grooves in the treated wood supports, which are protected from contact with the cable by heat shields of asbestos shellaced into the grooves. The winding is usually in the form of two back turn sections, thereby allowing the terminals of the coil to be brought out at the ends of the outside layer. This assures accessibility and ease of connection, and the removal of the leads from proximity to the core. Two turns at each end of the winding are given extra spacing for the purpose of additional insulation. The final turn at each end of the coil is securely held in place by alloy clamps bolted to the supports. The wood is protected from contact with the clamps by shields of asbestos. The ends of the cable between the two sections are welded by the oxy-acetylene process.

Ques. What are its essential features of construction?

Ans. It consists of bare stranded cable wound around a concrete core and held in place by wooden supports as shown in fig. 2,243.

In order to avoid the prohibitive expense of high voltage insulation. the reactance coil is designed for the low tension circuit. This requirement prohibits the use of a magnetic core which, if economically designed for normal operation, would become saturated at higher densities, or, if designed large enough to avoid saturation at short circuit conditions, would become prohibitive in cost and dimensions.

The elimination of all magnetic material from the construction of the concrete core reactance permits of no saturation, and assures a straight line voltage characteristic at all current loads.

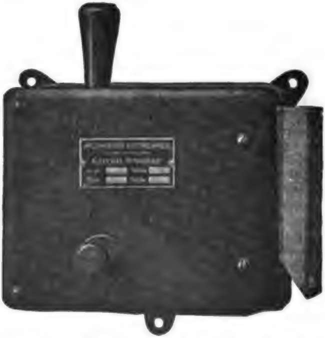


FIG. 2,244.—**Westinghouse magnetic blow out circuit breaker,** designed for the protection of street railway and electric locomotive equipments; it serves the combined purpose of fuse block and canopy switch. **The contact tips** *are surrounded by a moulded arc chute which confines and directs the arc until the magnetic blow out extinguishes it.* The current carrying contacts consist of copper strips separated by air spaces. An auxiliary contact or "arcing tip" at the end of the switch lever takes the burning of the arc when the breaker opens, and thus confines the burning to a very small piece which can be easily removed and replaced at small cost. The hand tripping lever and the resetting lever have insulated handles, so that they can be safely handled, even in the dark.

Ques. Where is the proper location for a current limiting reactance?

Ans. As near the alternator as possible.

Ques. Why?

Ans. To lessen the possibility of a short circuit occurring between the reactance and the alternator.

Ques. Beside limiting the current, what other service is performed by the reactance?

Ans. It protects the alternator from high frequency surges coming in from the outside, and limits the current from other machines on the same bus.

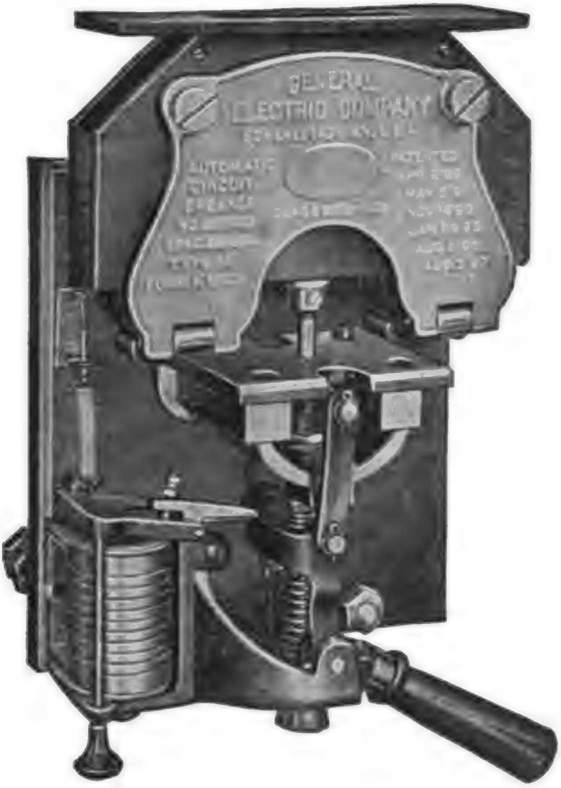


FIG. 2,245.—General Electric magnetic blow out circuit breaker. This type may be used in air or water tight boxes and is peculiarly adapted for service where the arc must be confined.

Circuit Breakers.—The importance of circuit protective devices, commonly called circuit breakers, is fully recognized. The duty of a circuit breaker is to protect the apparatus in an electrical circuit from undesirable effects arising from abnormal conditions, by automatically breaking the circuit. Accordingly a circuit breaker must comprise a switch in combination with electrical control devices designed to act under abnormal conditions in the circuit.

A circuit breaker is *a device which* **automatically** *opens the circuit in event of abnormal conditions, in the circuit.*

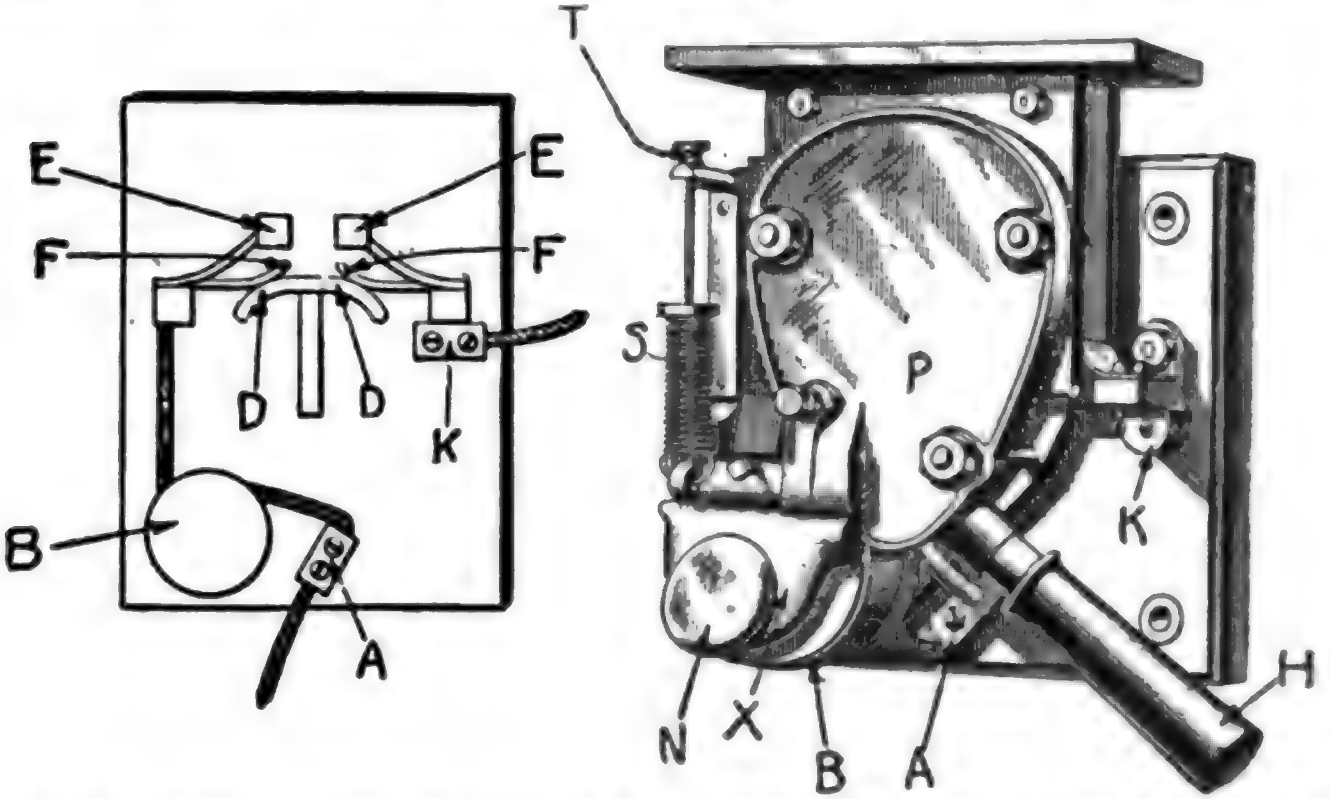


FIG. 2,246.—Magnetic blow out circuit breaker. This is a direct current breaker in which the final break occurs in a magnetic field. **It is a principle in electromagnetics** *that a conductor carrying a current in a magnetic field will tend to move in a direction at right angles to the field.* The arc set up on breaking a circuit constitutes a conductor, and in magnetic blow out circuit breakers, as generally manufactured, there is an electromagnet, energized by the current to be broken, which produces a field in the neighborhood of the arc, with the result that the arc moves outward, and so becomes attenuated and is finally extinguished. The form shown in the figure is used on cars equipped with heavy motors. When so used, it is in many cases mounted in a box with the handle H projecting at one end. A and K are the terminals of the breaker and B is the tripping coil, which also serves to set up the magnetic field necessary for blowing out the arc. X is the armature of coil B and is pulled down against the action of the spring S whenever the current exceeds that for which the breaker is set. The tripping current is adjusted by means of nut T. The iron plate P and a similar one back of it are magnetized by the current in coil B, and as the break takes place between these two poles, the arc is promptly extinguished by the field that exists there. **In operation,** A and K are the terminals, D D is a contact that is forced up against F, F when the breaker is set. The current then takes the path A–B–F–D D–F–K. **When the breaker trips,** the contact piece D D flies down and the tendency is for an arc to form between F, F; the magnetic field blows the arc upwards, and whatever burning takes place is on the contacts E, E, which are so constructed that they may be readily renewed. **To trip the breaker by hand,** the knob N is pressed.

In the design of circuit breakers, there are several methods used to effect the rupturing of the arc between contacts when opened on heavy overload, such as

1. Magnetic blow out; 2. Thermal break; 3. Carbon break.

In the magnetic blow out type, the arc is extinguished between auxiliary contacts confined by a chute in which the arc is rapidly blown out due to a powerful magnetic field from one or more electromagnets. This type may be used in air or water-tight boxes and is peculiarly adapted for service where the arc must be confined.

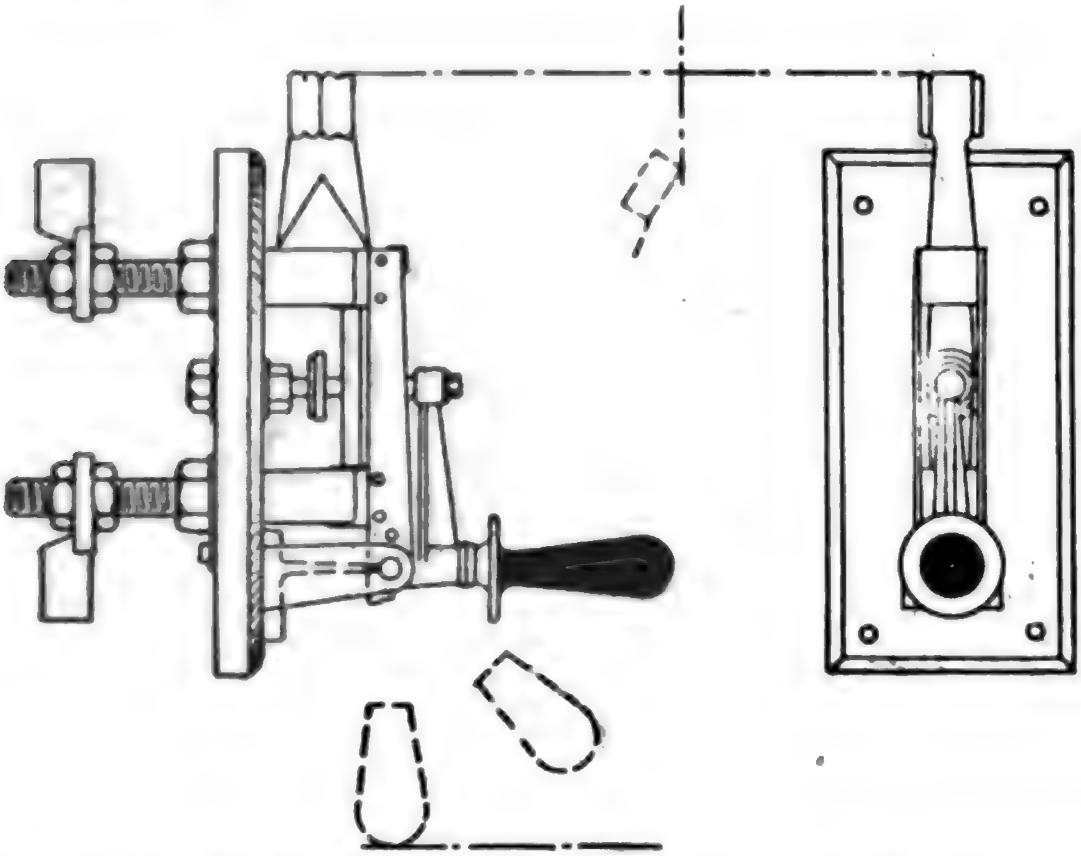


FIG. 2,247.—**Thermal overload circuit breaker.** **In construction** two contact blocks are fixed rigidly to, but insulated from, the switch arm. They are connected electrically by two parallel strips of suitable metal, each fitted with a steel catch piece. **When the switch is closed** the strips are sprung apart over a fixed catch, and the full rated current does not release the catch. Overload causes the strips to move apart, and the circuit breaker flies off under the action of a spring.

In a carbon break type, the arc is finally ruptured between carbon break contacts. The breaking of the circuit is accomplished progressively, that is to say, it is done in three stages, by several sets of contact, known respectively as

1. The main contacts;
2. The intermediate contacts;
3. The carbon contacts.

In operation, as the circuit breaker acts to break the circuit, first the **main** *contacts*, separate, then the **intermediate** *contacts*, and finally the **carbon** *contacts* between which the arc is ruptured.

Ques. What is the object of the intermediate contacts?

Ans. To prevent the forming of an arc on the main contacts.

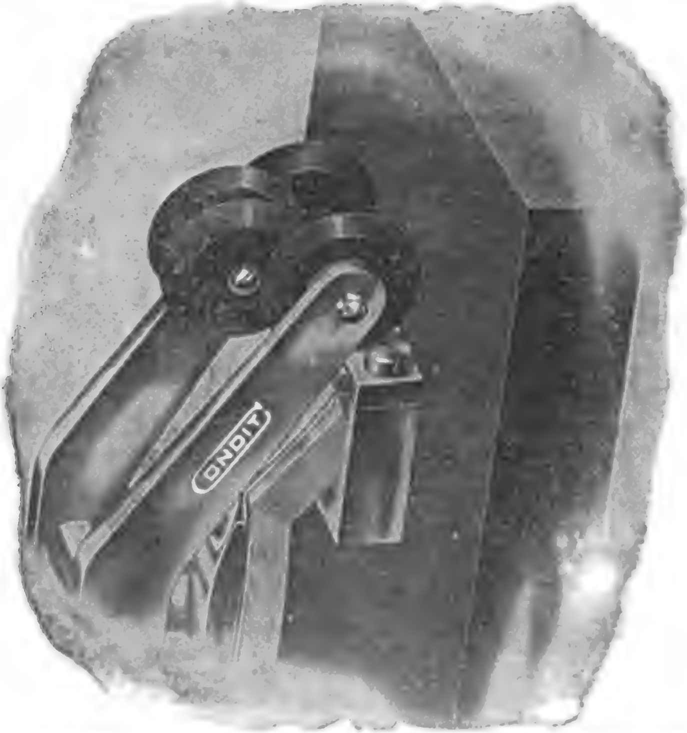


FIG. 2,248.—Carbon break discs of Condit circuit breaker. The two pairs of similar discs which slide past each other are so arranged that these surfaces coincide at the instant the intermediate contact separate after which, as the contact arm opens further, they gradually disengage.

Ques. What is the object of the carbon contacts?

Ans. First to protect the intermediate contacts by providing a path for the current after the intermediate contacts separate, and 2, to "slow down" the current by means of the considerable resistance of the carbon, thus reducing to a minimum the arc which is formed when the carbon contacts separate.

Ques. How is the automatic operation of a circuit breaker usually accomplished ?

Ans. Usually through the medium of a solenoid, or electro magnet energized by current from the circuit controlled by the breaker.

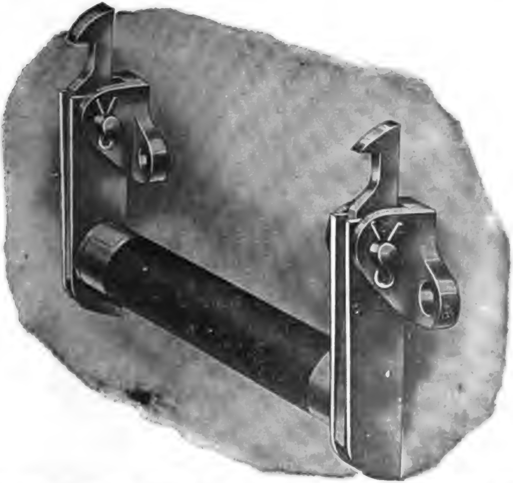
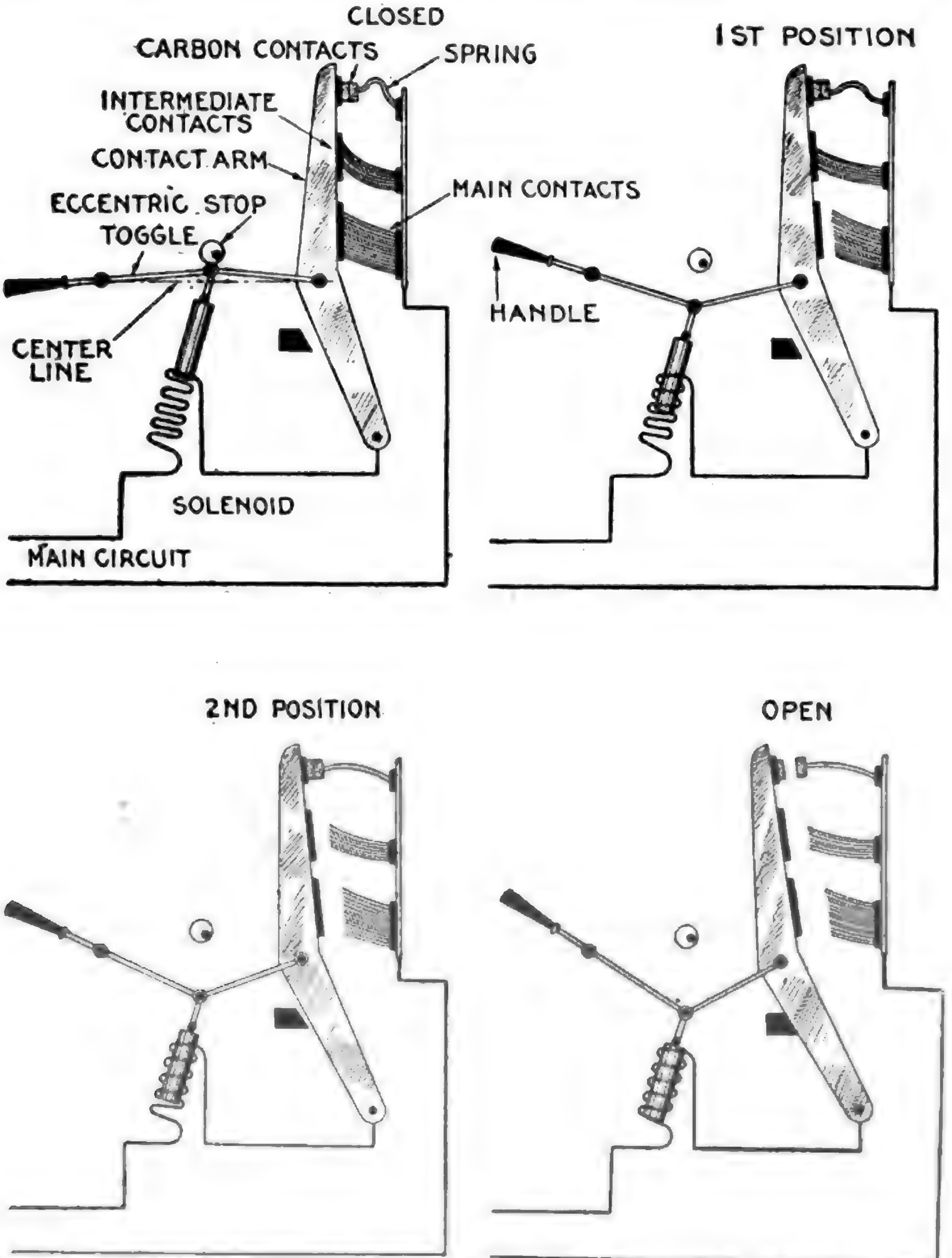


FIG. 2,249.—Mechanically connected insulated latches used on Condit circuit breakers to produce inter-locking tripping.

The essential features of construction and operation of a circuit breaker is shown in the elementary diagrams, figs. 2,250 to 2,253. **In construction** as shown in fig. 2,250 it consists essentially of three sets of contacts, a swinging contact arm which is set in the closed position by the handle operating through the toggle joint, the movement of which is limited in the closing direction by the stop. The latter is made adjustable by an eccentric pin or equivalent. Connected to the toggle is the plunger of the solenoid whose winding is energized by current from the circuit which the circuit breaker is to control.


CLOSED
CARBON CONTACTS
SPRING
INTERMEDIATE CONTACTS
CONTACT ARM
ECCENTRIC STOP
TOGGLE
MAIN CONTACTS
CENTER LINE
SOLENOID
MAIN CIRCUIT
1ST POSITION
HANDLE
2ND POSITION
OPEN

FIGS. 2,250 to 2,253.—Elementary diagrams illustrating the operation of a carbon circuit breaker of the overload type, showing the progressive opening of such device. Fig. 2,250, closed position; fig. 2,251, main contacts open; fig. 2,252, intermediate contacts open; fig. 2,253, carbon contacts open, circuit broken.

In operation, the circuit is closed by hand by turning the handle downward to the position shown in fig. 2,250, that is as far as it will go.

Since the toggle has passed the center line the arm will be held normally in this position because of the spring action of the contacts. Now, if the current rise above a pre-determined limit, the pull exerted by the solenoid will overbalance the tendency of the toggle to remain in the closed position, and pull the two toggle links downward below the center line, drawing the contact arm back and breaking the circuit.

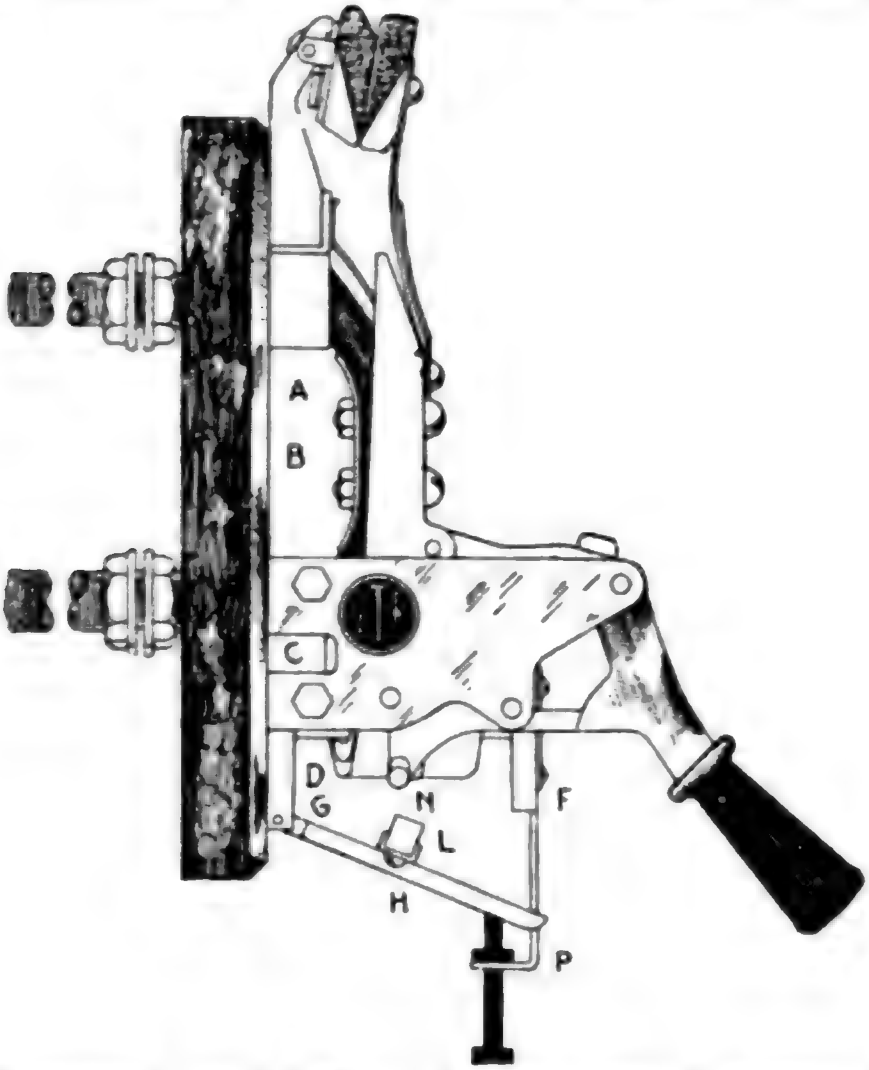


FIG. 2,254.—I-T-E overload circuit breaker. **In operation:** the current from one side of the circuit enters the circuit breaker at A, passing through the laminated bridge B to contact block C, thence through coil D and terminal E to the motor. The coil D surrounds a magnetic core, having pole pieces F and G and armature H. The effect of the current in the coil is to energize the magnet, thus tending to lift the armature against the force of gravitation. The volume of current required to trip the circuit breaker is determined by the position of the armature, which is subject to ready adjustment, and is indicated on the calibration plate P. From the opposite side of the line, the current enters at I, passing downward through the laminated bridge member J, into terminal K, whence it passes out to the motor. When the current passing through the circuit breaker attains sufficient volume, the force generated by the magnetic coil overcomes the weight of the armature H; and the latter is drawn upward toward the pole pieces with constantly increasing force, until the insulated projections L and M strike against the respective restraining latches N and O, thereby releasing the two switch members, which at once open in response to the force supplied by the spring of the contact members and auxiliary springs provided for the purpose. Positiveness in opening is further assured by the blow of the armature, which is added to the other opening forces; hence, the heavier the overload, the more violent the blow and the quicker the circuit breaker opens; or the greater the current the more promptly it is interrupted. This is the **I-T-E or Inverse Time Element principle.**

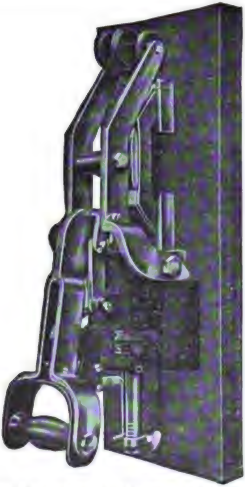


Fig. 2,255.—Condit 600 volt, 1,200 ampere, single pole, type K, circuit breaker with pull down handle.

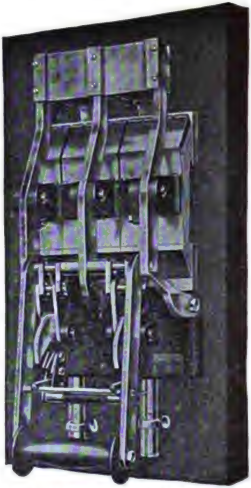


Fig. 2,256.—Condit 600 volt, 6,000 ampere, single pole, switch board mounting, circuit breaker, with pull down handle.

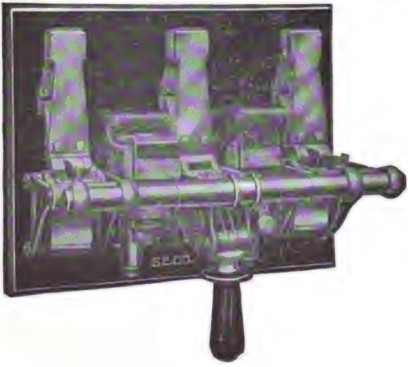


Fig. 2,257.—General Electric triple pole, overload, circuit breaker, with two overload coils, capacity 300 amperes, 480 volts.

The progressive action which takes place during this operation is shown in figs. 2,250 to 2,253 in which the main contacts separate first, then the intermediate, and finally the carbon contacts as mentioned before.

Ques. What name is given to this type of circuit breaker?

Ans. It is called an overload circuit breaker.

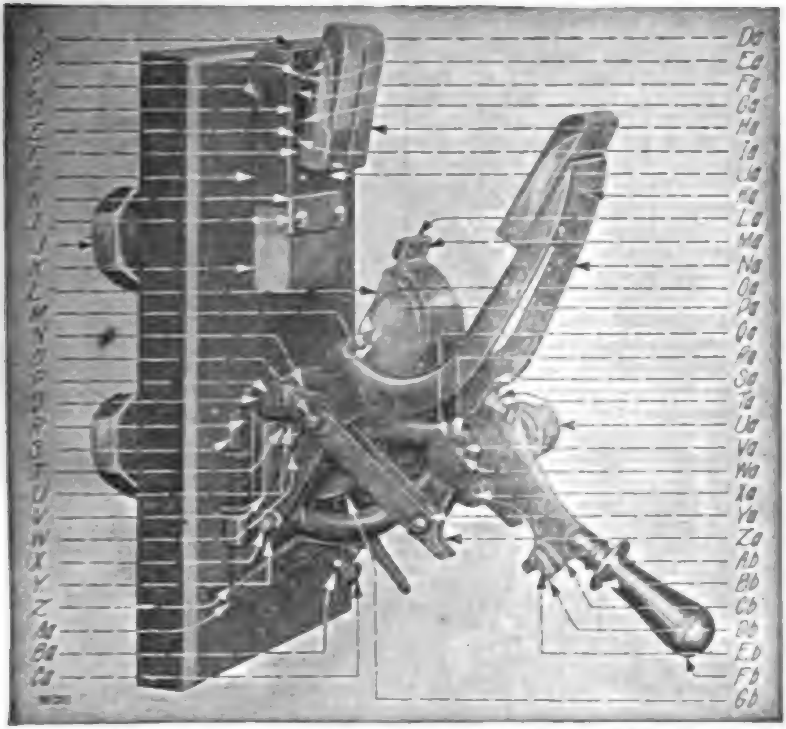
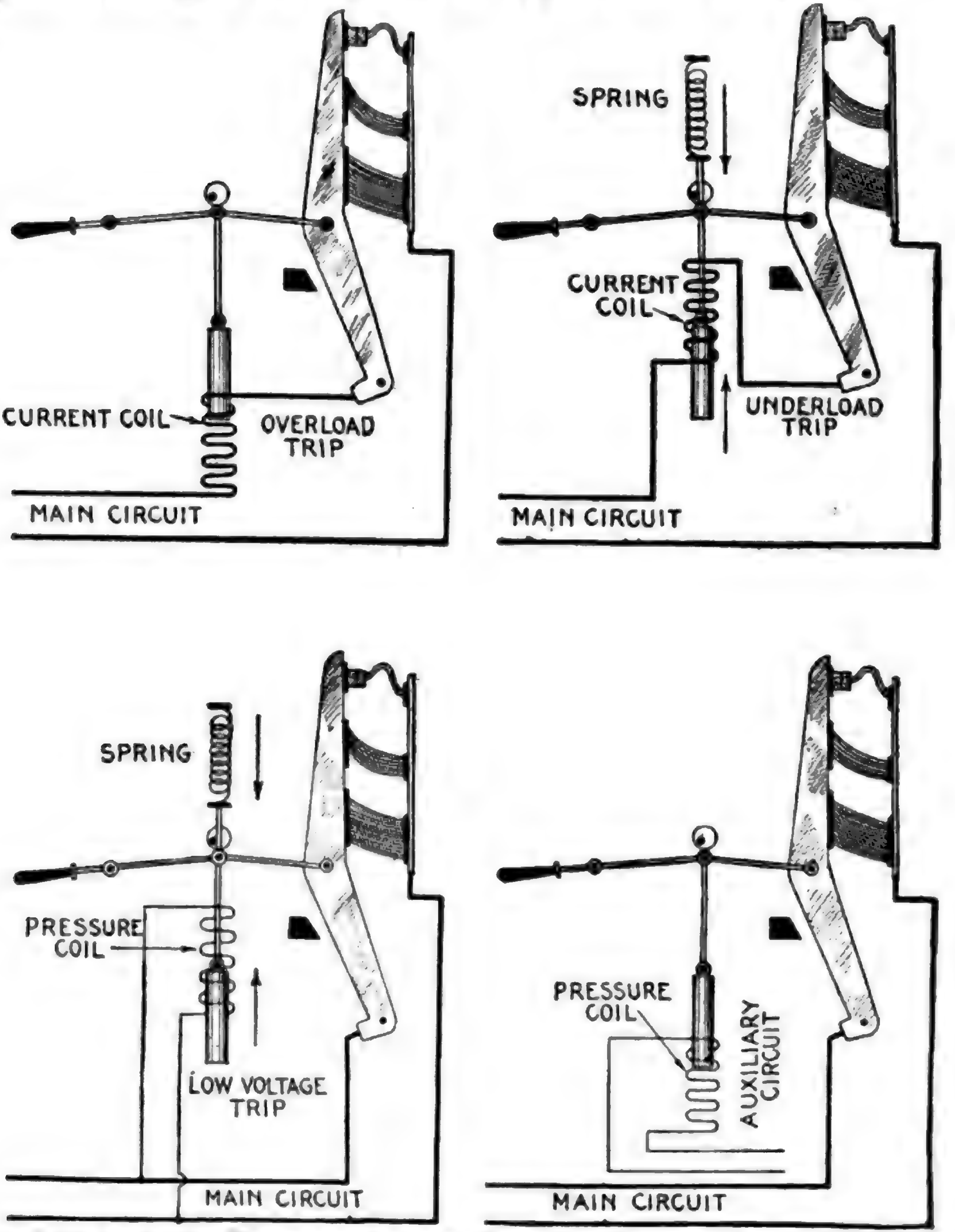


FIG. 2,258.—Parts of General Electric 2,000 ampere 650 volt circuit breaker. A, cover for secondary contact bracket; B, spring washer for Ea.; C, pin for links and G; D, spring for carbon support; E, plate for F; F, carbon support; G, secondary contact bracket; H, contact plate; I, screw for H; J, nut for K and W; K, contact stud, upper; L, laminated brush, complete with support; M, leather buffer for L; N, main link; O, pin for Na and La left hand and Cb and Na right and left hand; P, screw for N and magnet frame shaft; Q, washer for N and magnet frame shaft; R, screw for S and V; S, index plate; T, plate for Gb; U, screw for T; V, magnet frame; W, contact stud, lower; X, pin for Cb, Na and V; Y, washer for X and O; Z, calibrating screw with thumb nut; Aa, armature with contact plate; Ba, catch lever complete with catch Ca, button handle for Ba; Da, spring cotter for Ea; Ea, pin for F and Fa; Fa, operating link for G; Ga, pin for D; Ha, carbon holder with copper and carbon contacts; Ia, flexible connections for G and F; Ja, screw for G and flexible connection plate; Ka, screw for Na and Ha; La, copper secondary contact; Ma, screw for La; Na, secondary contact lever; Oa, cross bar for Na; Pa, screw for L and M; Qa, secondary toggle link (left hand); Ra, spring cotter for Wa and O; Sa, brush lever; Ta, buffer for Cb and Sa; Ua, secondary toggle link (right hand); Va, washer for Wa; Wa, pin for Cb, Qa, Ua and N; Xa, pin for Sa and Cv; Ya, spring cotter for all pins, except Wa, catch lever pin and buffer; Za, secondary contact link; Ab, washer for Fb; Bb, guard for Fb; Cb, handle lever; Db, catch for Cb; Eb, screw for Db; Fb, handle with stud; Gb, secondary connection.

Automatic Features.—There are three methods of connecting the winding of the solenoid, or *trip coil* as it is called:


CURRENT COIL
OVERLOAD TRIP
MAIN CIRCUIT
SPRING
CURRENT COIL
UNDERLOAD TRIP
MAIN CIRCUIT
SPRING
PRESSURE COIL
LOW VOLTAGE TRIP
MAIN CIRCUIT
PRESSURE COIL
AUXILIARY CIRCUIT
MAIN CIRCUIT

FIGS. 2,259 to 2,262.—Elementary diagrams illustrating the various methods of electromagnetic control for circuit breakers. Fig. 2,259, overload trip; fig. 2,260, underload trip, fig. 2,261, low voltage trip; fig. 2,262, control from auxiliary circuit by means of a "relay."

1. In series with the main circuit;
2. In shunt with the main circuit;
3. In shunt with an auxiliary circuit.

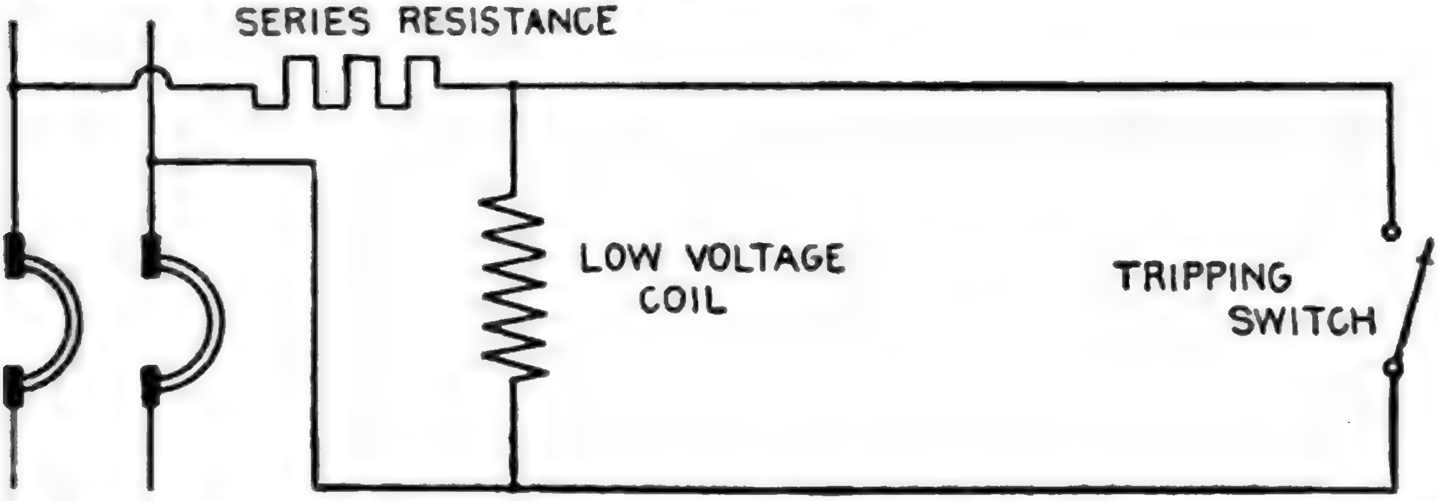

SERIES RESISTANCE
LOW VOLTAGE COIL
TRIPPING SWITCH

FIG. 2,263.—Diagram of General Electric low voltage trip with tripping switch *normally* open.

The automatic controls arising from these connections give various kinds of protection to the circuit and are known as

1. Overload trip;
2. Underload trip;
3. Low voltage trip;
4. Auxiliary circuit trip.

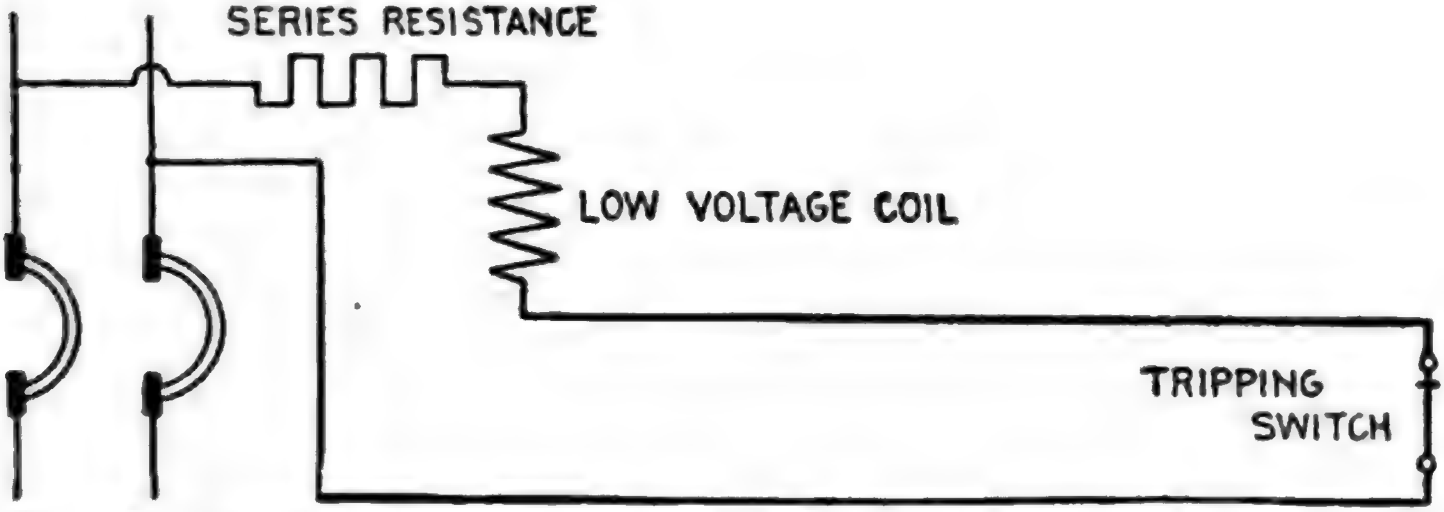

SERIES RESISTANCE
LOW VOLTAGE COIL
TRIPPING SWITCH

FIG. 2,264.—Diagram of General Electric low voltage trip, with tripping switch *normally* closed.

Ques. What is the object of the overload trip?

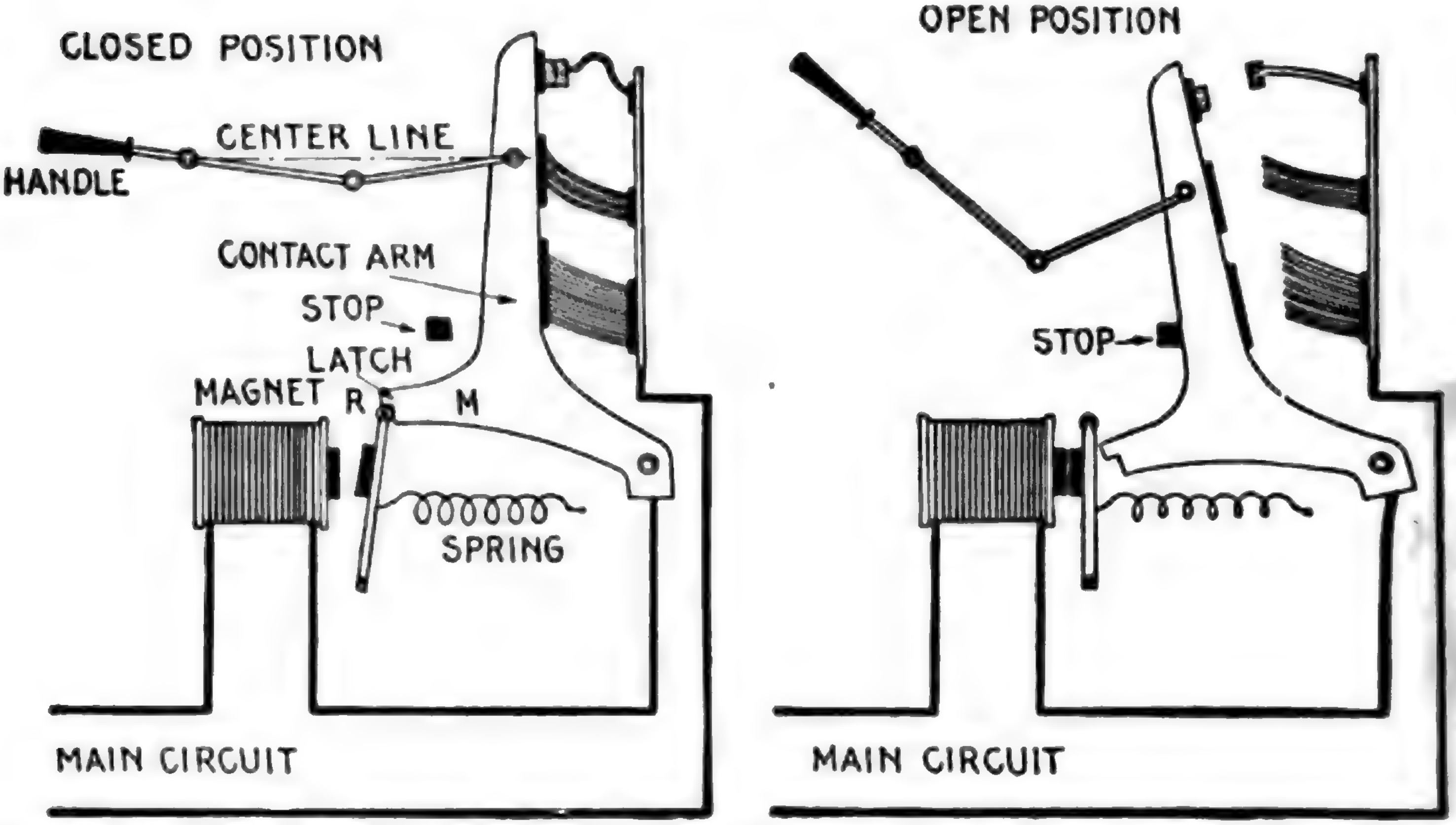
Ans. It is intended to open the circuit when the current exceeds a predetermined value.

Ques. What modifications are made in the mechanism shown in the elementary diagrams?

Ans. Sometimes a latch is used in place of the toggle and a magnet in place of the solenoid as in figs. 2,265 and 2,266.

Ques. Why is a magnet used in combination with a latch?

Ans. Because with this arrangement very little movement is required to trip the breaker, and for such conditions, a magnet is more efficient than a solenoid.



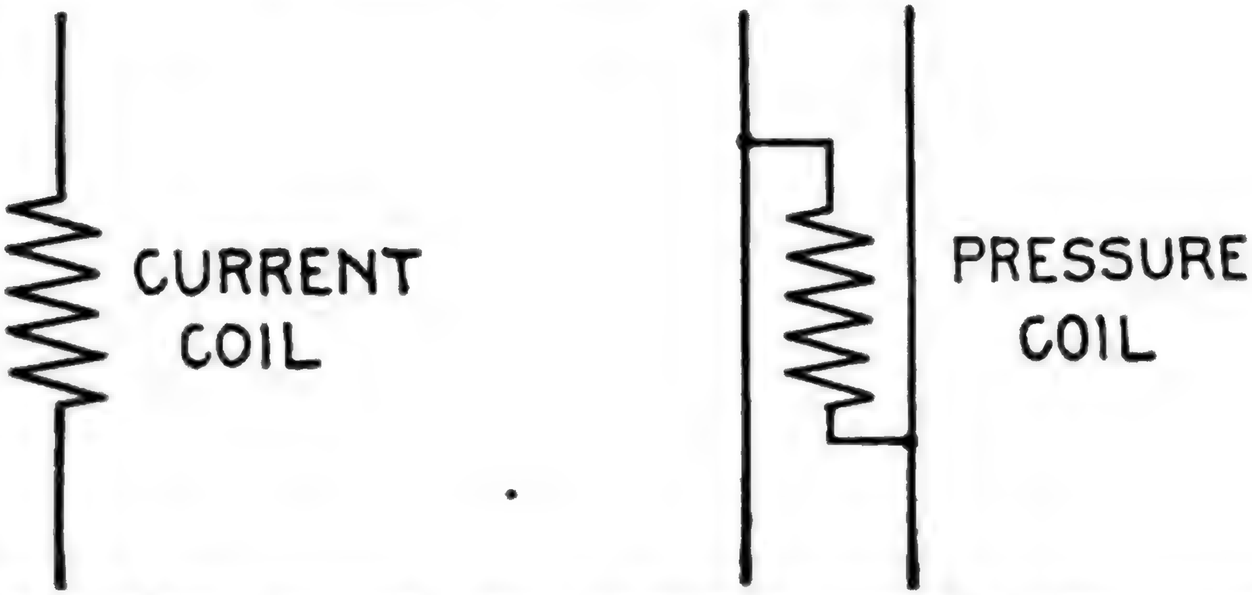
FIGS. 2,265 and 2,266.—Circuit breaker with automatic control mechanism consisting of **magnet and latch;** views showing breaker in open and closed positions, and essential features. The toggle is used to obtain sufficient leverage to easily close switch against the pressure of the brush contacts but not to lock switch, this being done by the latch as shown, the latter closing by the action of a spring, there being a roller R at the end which engages the arm to reduce friction. **In operation,** when the current exceeds a predetermined limit the magnet attracts the latch and releases the contact arm. The brush contacts which are exerting pressure against the contact arm, rapidly push it away, and assisted by gravity, the arm flies open to the position shown in fig. 2,266.

Ques. How does the latch arrangement work?

Ans. When the proper current is reached, the magnet pulls open the latch and the contact arm of the breaker moves by the force of gravity or other means and opens the circuit.

Ques. How does the underload trip operate?

Ans. The same as the overload type except that they operate on a diminution of current instead of an excess.



Figs. 2,267 and 2,268.—Positions in circuit of *current* and *pressure* coils of circuit breakers.

Ques. Describe the no voltage trip.

Ans. The energy for the trip of this breaker is derived from a high resistance or fine wire coil which is arranged to be placed directly across the line, in operation, when the current flowing hrough the circuit falls below a predetermined valve, the energy f the coil is insufficient to counteract the force of a spring, which hen trips the breaker.

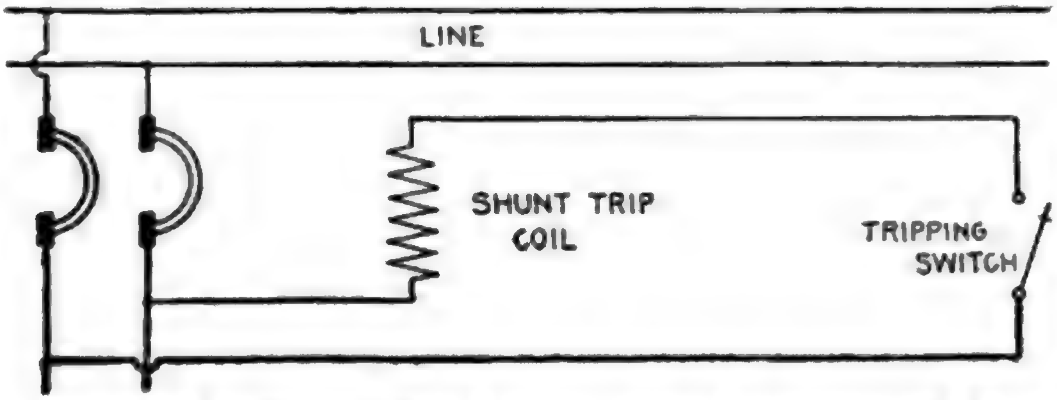


Fig. 2,269.—Diagram of General Electric shunt trip with coil connected beyond breaker and thrown out of circuit after tripping.

Ques. Describe the auxiliary circuit trip.

Ans. A pressure coil is used which is energized by current from an auxiliary circuit. The coil is only *momentarily* energized,

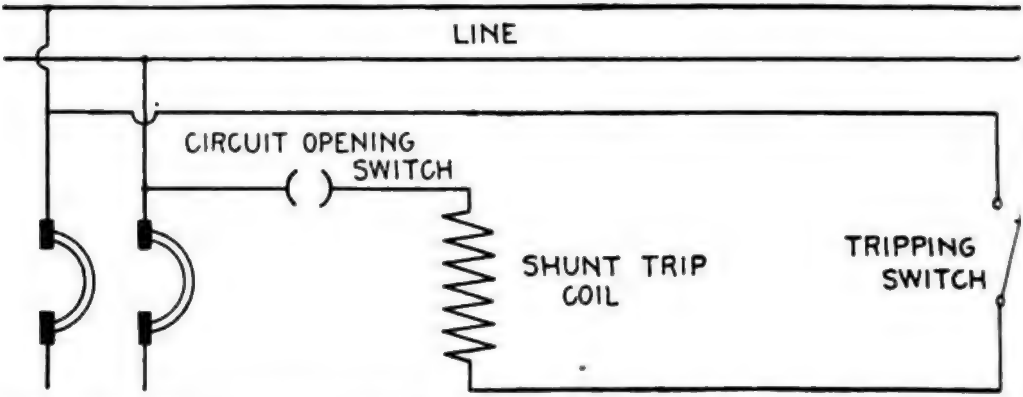


Fig. 2,270.—Diagram of General Electric shunt trip with auxiliary circuit opening, switch t throw coil out of circuit after tripping.

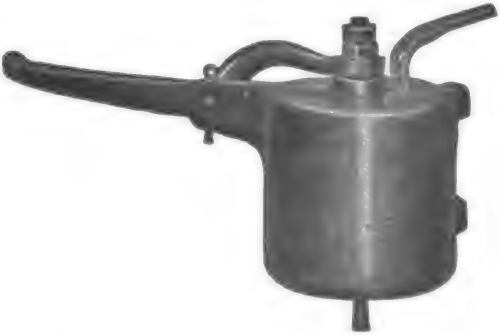


Fig. 2,271.—General Electric shunt trip attachment. The shunt trip attachment has been designed to provide for conditions under which the low voltage attachment cannot be successfully applied. It resembles the low voltage attachment in construction, but differs in that it trips the circuit breaker when energized. The shunt trip should be allowed to remain only momentarily in circuit; hence it should be so connected that the opening of the circuit breaker immediately disconnects it from the circuit. Whenever it is impossible to connect the shunt trip in this manner, the circuit opening auxiliary switch should be used in connection with it.

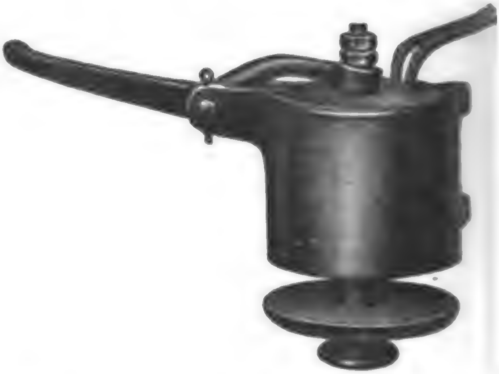


Fig. 2,272.—General Electric low volt attachment for circuit breakers. This lo voltage trip is designed to operate t circuit breaker when the line voltage dro to approximately 50 per cent or less of th normal voltage. It should be noted th the coil is always in circuit, as is the ca with the overload and underload coils, a that it operates with the *releasing* of i armature. It is always necessary to u a fixed amount of resistance (dependi upon the voltage of the system) in seri with the low voltage release. The lo voltage release performs the functions of shunt trip coil when used in conjuncti with a push button, auxiliary switch speed limiting device, and is general preferred to the shunt trip attachment.

by push button, relay or other control, as distinguished from the preceding types, in which the coil is *constantly* energized.

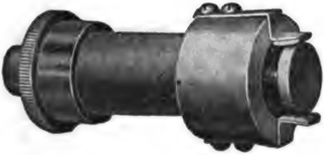


FIG. 2,273—General Electric **circuit opening** *auxiliary switch*. This switch opens an auxiliary circuit when the circuit breaker opens, and is intended to be used in connection with a shunt trip attachment to insure the immediate disconnection of the shunt coil from the circuit. It may also be employed to serve other purposes, such as tripping another circuit breaker having a low voltage attachment, and permitting another circuit breaker to remain closed only when the circuit breaker equipped with the auxiliary switch is open.

Ques. What other name is given to the auxiliary circuit trip?

Ans. It is sometimes called the shunt trip, though ill advisedly so.

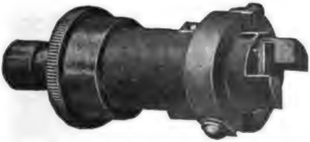


FIG. 2,274.—General Electric **circuit closing** *auxiliary switch*. This switch closes when the circuit breaker opens, and may be used to announce the automatic opening of the circuit breaker through the means of an indicating lamp or an alarm bell. It is often necessary to arrange one circuit breaker so that, in opening, it will trip others. This may be accomplished by using a circuit closing auxiliary switch in connection with a low voltage or shunt trip attachment on the circuit breakers to be tripped. The construction of this type of switch is such that it may be opened by hand after the circuit breaker opens, but it is automatically reset when the circuit breaker is closed.

Relays.—Oil break switches and carbon break circuit breakers are commonly used to open electrical circuits at some given overload and on short circuit. To secure additional protection under a variety of abnormal condition or to provide for a certain pre-determined operation or sequence of operations, relays may be employed.

A relay is defined as: *A device which* **opens** *or* **closes** *an*

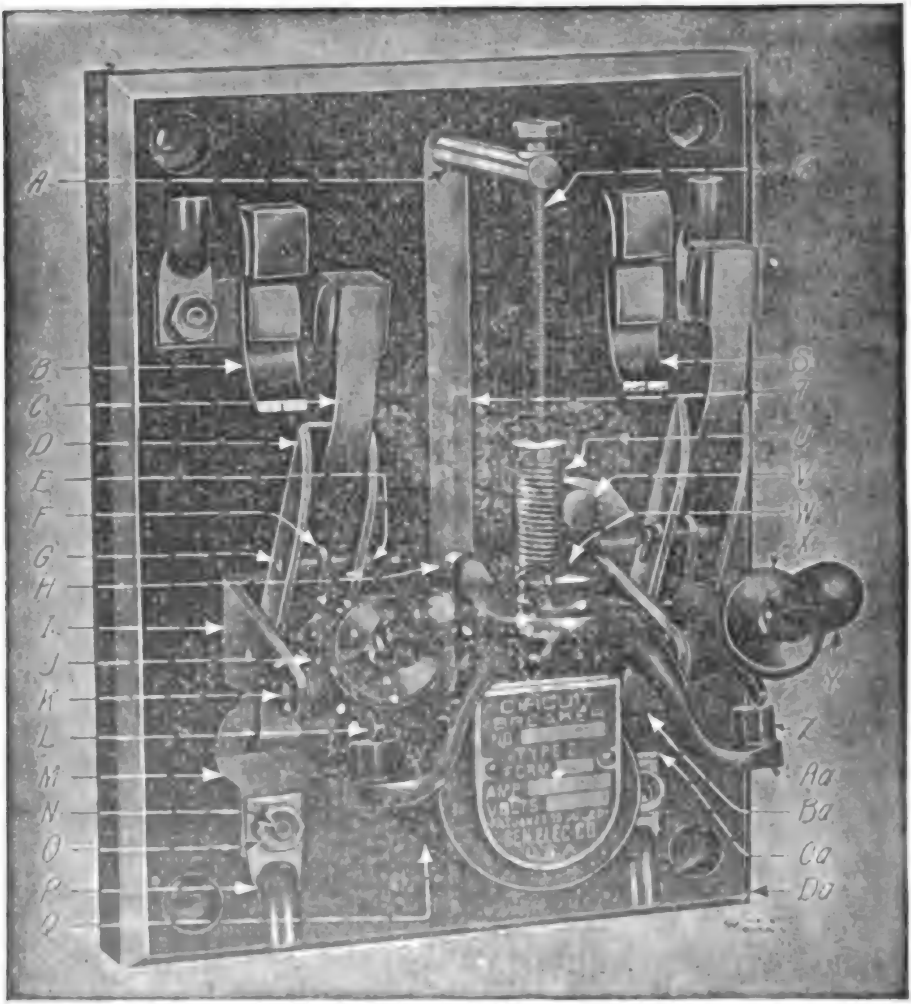


FIG. 2,275.—General Electric type C circuit breaker. Specially adapted to motor driven machine tool applications. For use in mills, machine shops, factories, foundries and office buildings. For general motor work, automobile charging outfits, storage batteries, rectifier sets, cranes, etc. List of parts: A, calibrating post; B, laminated contact; C, secondary contact spring; D, contact blade; E, cotter pin for G; F, toggle link; G, pin for D and F; H, stop for Aa; I, hinge frame; J, operating lever; K, pin for I and J; L, toggle link; M, connection; N, screw for M, O and P; O, nut for N and P; P, terminal; Q, tripping coil; R, calibrating screw; S, laminated contact; T, calibrating scale; U, calibrating spring; V, connection post; W, knob; X, washer for Y; Y, handle; Z, buffer; Aa, armature; Ba, laminated connection; Ca, connection; Da, base.

auxiliary circuit *under pre-determined electrical conditions in the main circuit.*

The object of a relay is generally to act as a sort of electrical multiplier, that is to say, *it enables a comparatively weak current to bring into operation a much stronger current.*

Ques. For what service are relays largely used?

Ans. They are employed in connection with high voltage switches where the small amount of energy derived from an ordinary instrument transformer is insufficient for tripping.

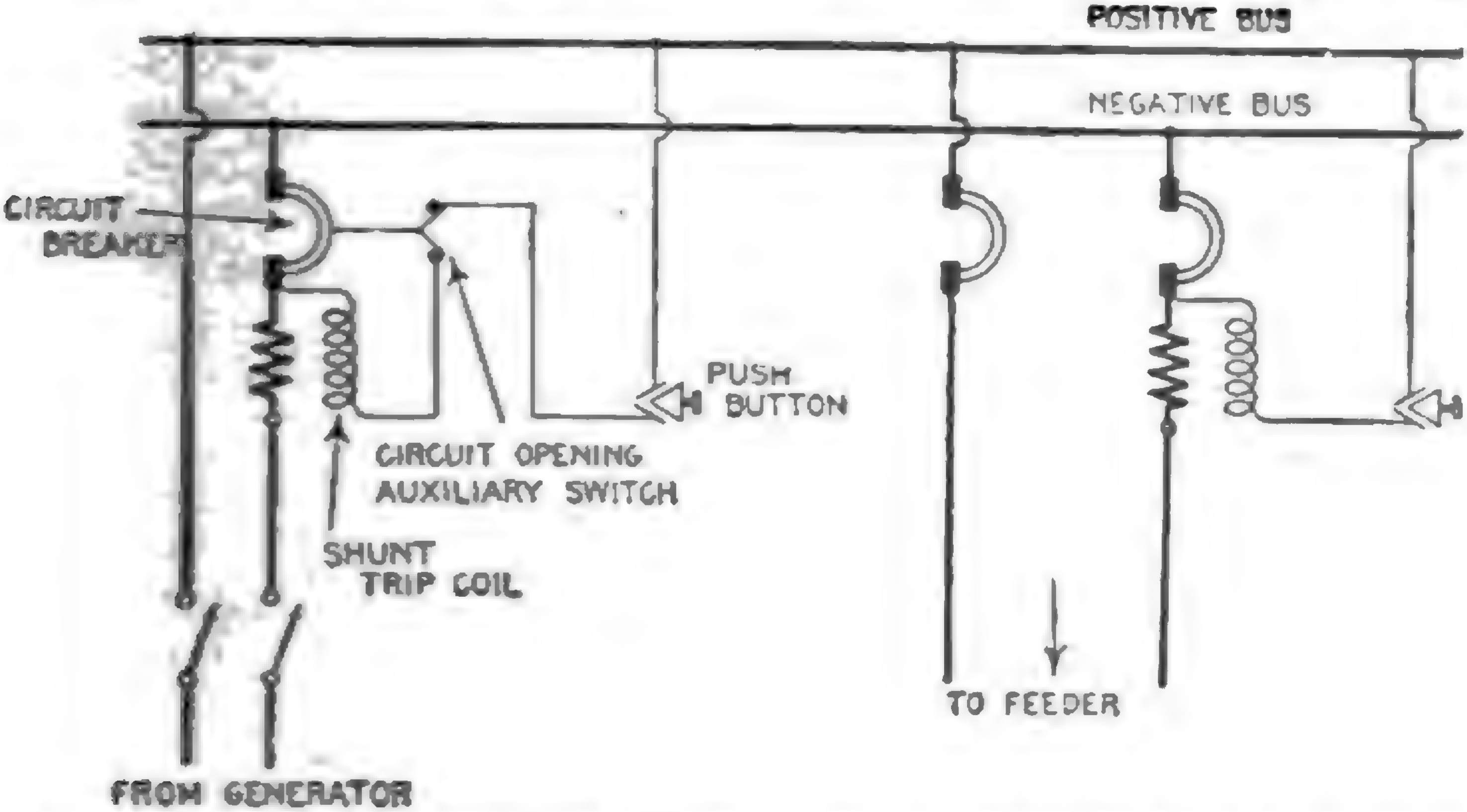

POSITIVE BUS
NEGATIVE BUS
CIRCUIT BREAKER
PUSH BUTTON
CIRCUIT OPENING AUXILIARY SWITCH
SHUNT TRIP COIL
TO FEEDER
FROM GENERATOR

FIG. 2,276.—Diagram of connections of General Electric shunt trip coil **with** and **without** circuit opening auxiliary switch.

The connections between relays and circuit opening devices are usually electrical. Combinations of this nature are extremely flexible since they permit the use of a number of devices, each having a different function, with a single circuit breaker or oil switch as well as with two or more switches, to secure the desired operation and protection.

Selection.—In all electrical installations protection of apparatus is important, but in some large central stations this is secondary to continuity of service.

To combine maximum protection without interruptions of service is not always possible, but these requirements can be approximated very closely by the use of reliable and simple controlling or protecting devices if proper care be taken to select the relays suited to the special conditions of the installation. To do this intelligently, a knowledge of the various types of relay is necessary.

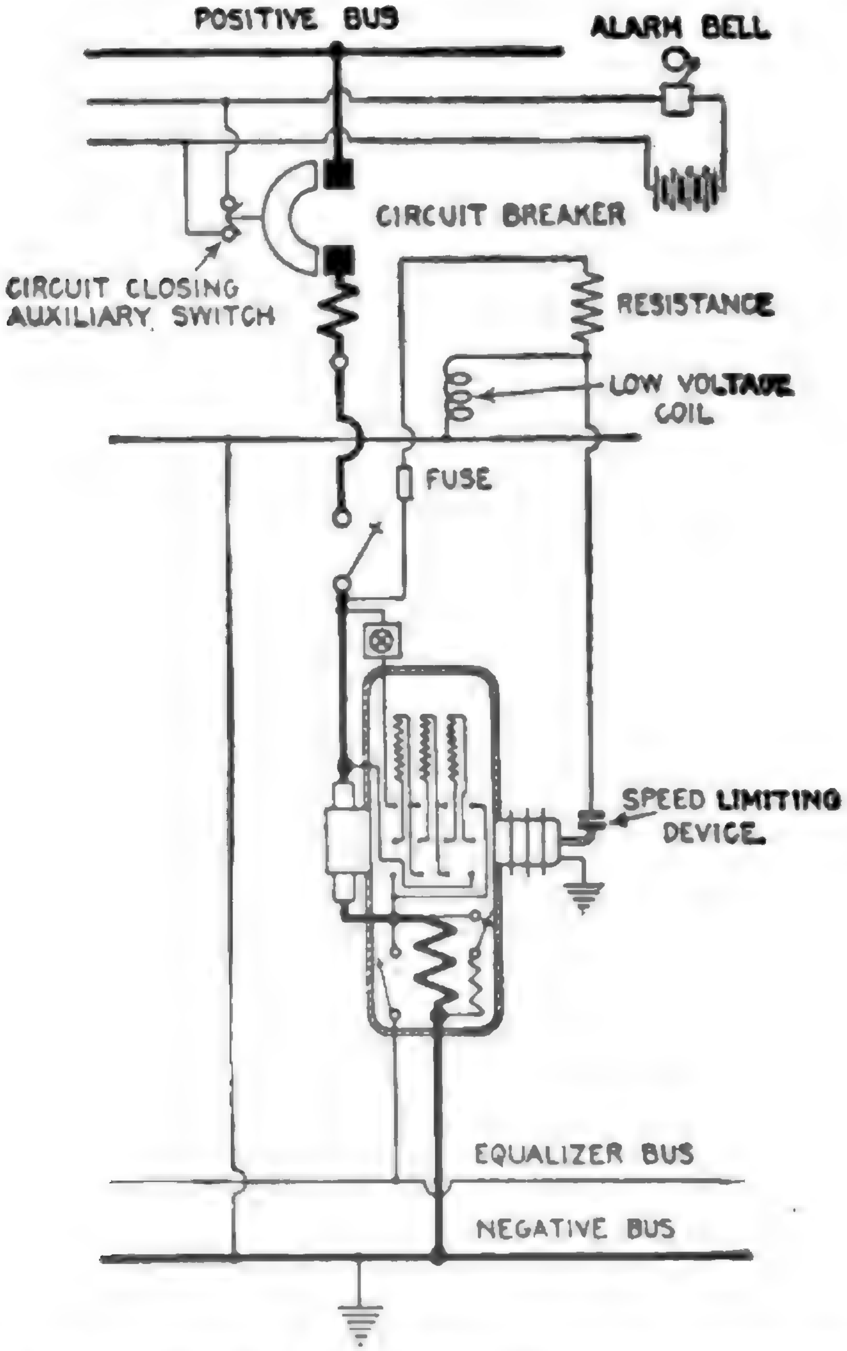

POSITIVE BUS
ALARM BELL
CIRCUIT BREAKER
CIRCUIT CLOSING AUXILIARY SWITCH
RESISTANCE
LOW VOLTAGE COIL
FUSE
SPEED LIMITING DEVICE
EQUALIZER BUS
NEGATIVE BUS

FIG. 3,073.—Diagram of connections of General Electric low voltage release coil when used with speed limiting device on rotary converter.

There is a multiplicity of types and a classification to be comprehensive, should, as in numerous other cases, be made from several points of view. Accordingly relays may be classified.

1. With respect to the nature of the service performed, as

   a. Protective;
   b. Regulative;
   c. Communicative.

2. With respect to the operating current, as

   a. Alternating current;
   b. Direct current.

3. With respect to the manner of performing their function, as

   a. Circuit opening;
   b. Circuit closing.

4. With respect to the operating current circuit, as

   a. Primary;
   b. Secondary.

5. With respect to the abnormal conditions which caused them to operate, as

   a. Overload;
   b. Underload;
   c. Over voltage;
   d. Low voltage;
   e. Reverse energy;
   f. Reverse phase.

6. With respect to the time consumed in performing their function, as

   a. Instantaneous (so called);
   b. Definite time limit;
   c. Inverse time limit.

7. With respect to the character of its action, as

a. Selective;
b. Differential.

8. With respect to whether it acts directly or indirectly on the circuit breaker, as

a. Main;
b. Auxiliary.

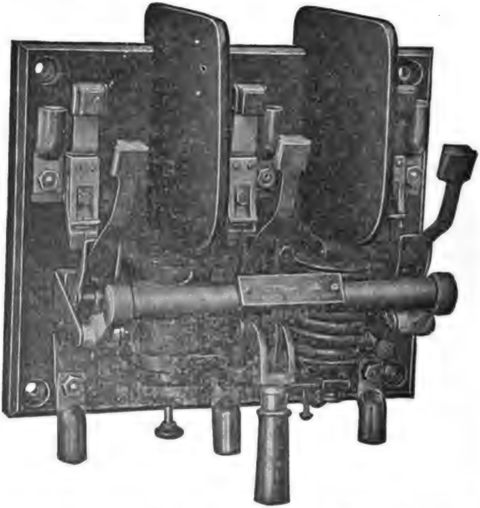


FIG. 2,278.—General Electric overload and low voltage type C circuit breaker for 600 volts or less. It has one overload, and one low voltage coil as shown. Screens are provided between contacts.

Protective Relays.—These are used to protect circuits from abnormal conditions of voltage, or current, which would be undesirable or dangerous to the circuit and apparatus contained therein.

Ques. How do protective relays operate?

Ans. They act in combination with automatic circuit breakers, operating when their predetermined setting has been reached, energizing the trip coil of the circuit breaker and opening the circuit.

Fig. 2,279 shows the principles of relay operation. When the current or pressure in the main circuit reaches the predetermined value at which the protective system should operate, the relay magnet attracts the pivoted contact arm and closes the auxiliary circuit; this permits current to flow from the current source in that circuit and energize the trip coil thus opening the main circuit.

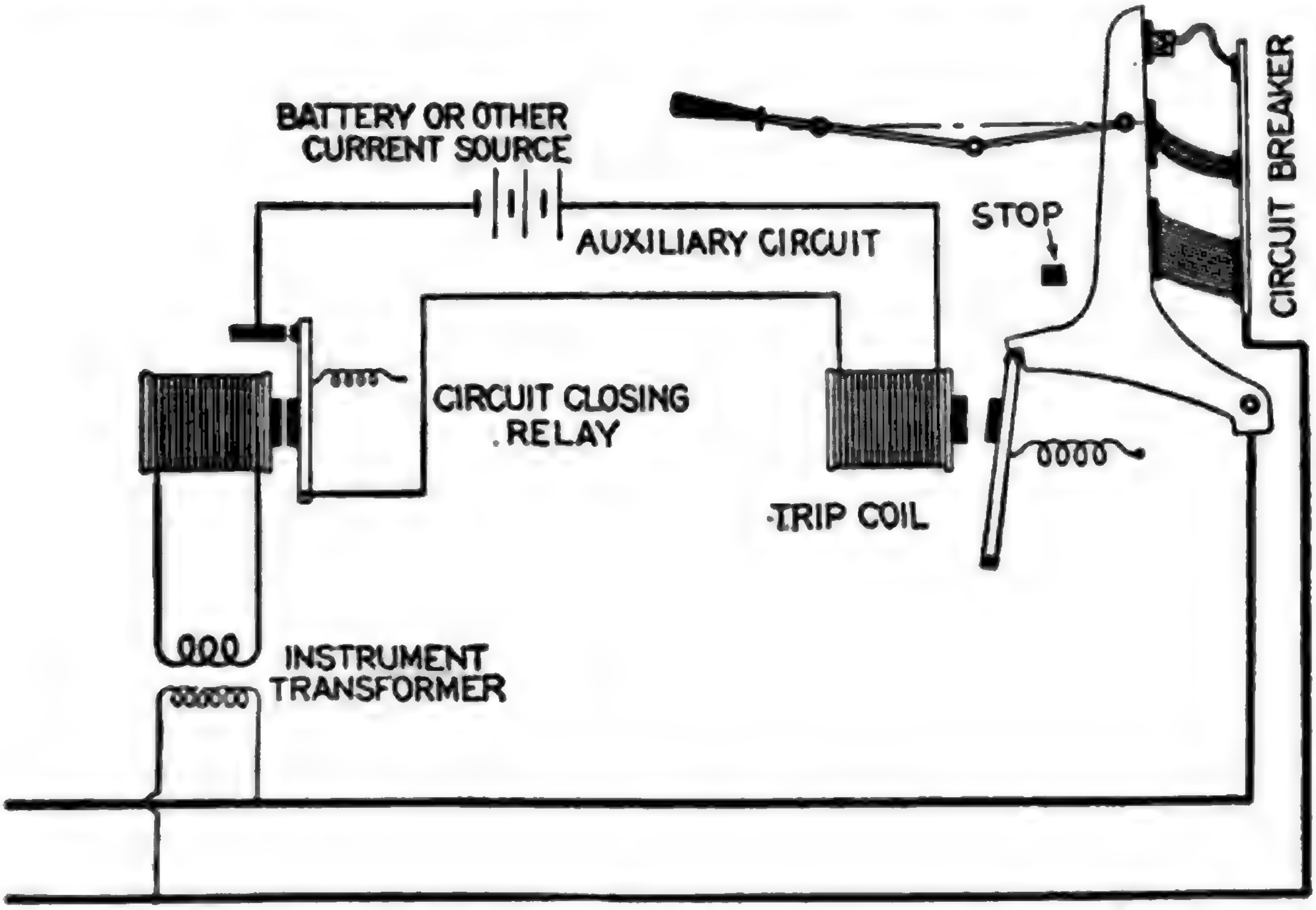

BATTERY OR OTHER CURRENT SOURCE
AUXILIARY CIRCUIT
STOP
CIRCUIT BREAKER
CIRCUIT CLOSING RELAY
TRIP COIL
INSTRUMENT TRANSFORMER

FIG. 2,279.—Diagram illustrating the operation of a **circuit closing relay.** When the predetermined abnormal condition is reached in the main circuit, the relay closes the auxiliary circuit, thus energizing the trip coil and opening the breaker.

Regulative Relays.—This class of relay is used to control the condition of a main circuit through control devices operated by a secondary circuit.

Ques. For what service are relays of this class employed?

Ans. They are used as feeder circuit or generator regulators.

Ques. How do they differ from protective relays?

Ans. They have differentially arranged contacts, that is to say, arranged for contact on either side of a central or normal position.

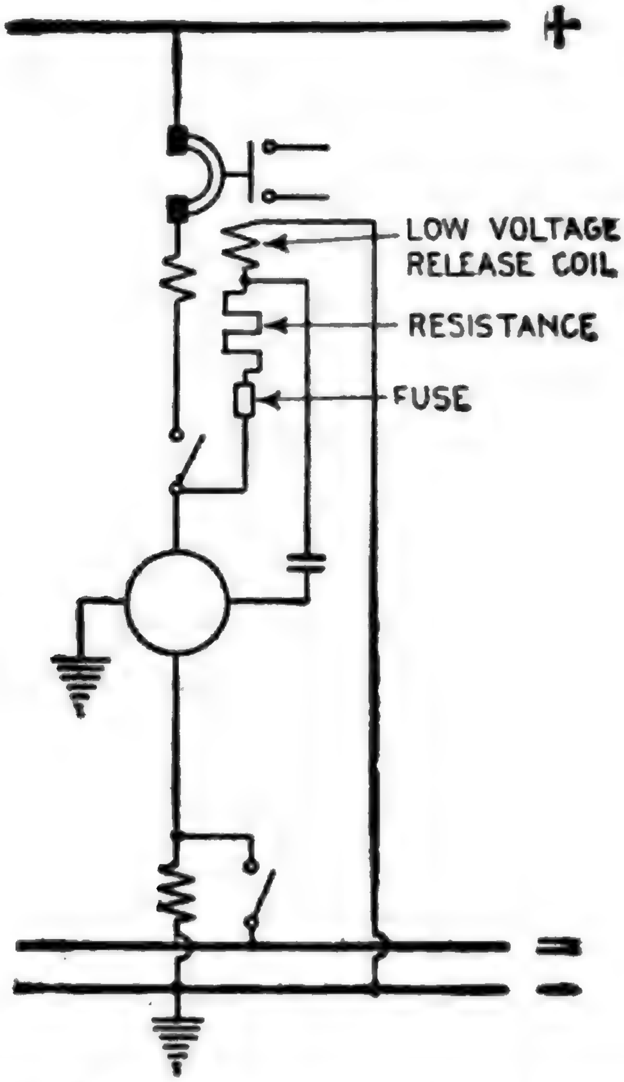


FIG. 2,280.—Diagram showing a railway synchronous converter protected by a single pole overload circuit breaker with low voltage release attachment and bell alarm switch. The low voltage attachment trips the breaker on failure of direct current voltage also when speed limit device closes. Internal troubles are taken care of by the alternating current automatic devices (not shown).

Communicative Relays.—These are used for signalling in a great variety of ways for indicating the position of switching apparatus or pre-determining the condition of electric circuits.

A.C. and D.C. Relays.—As here used, the classification refers to the kind of current used on the auxiliary circuit. In some cases direct current is used to energize the trip gear of the circuit breaker or oil switch, and in others, alternating current.

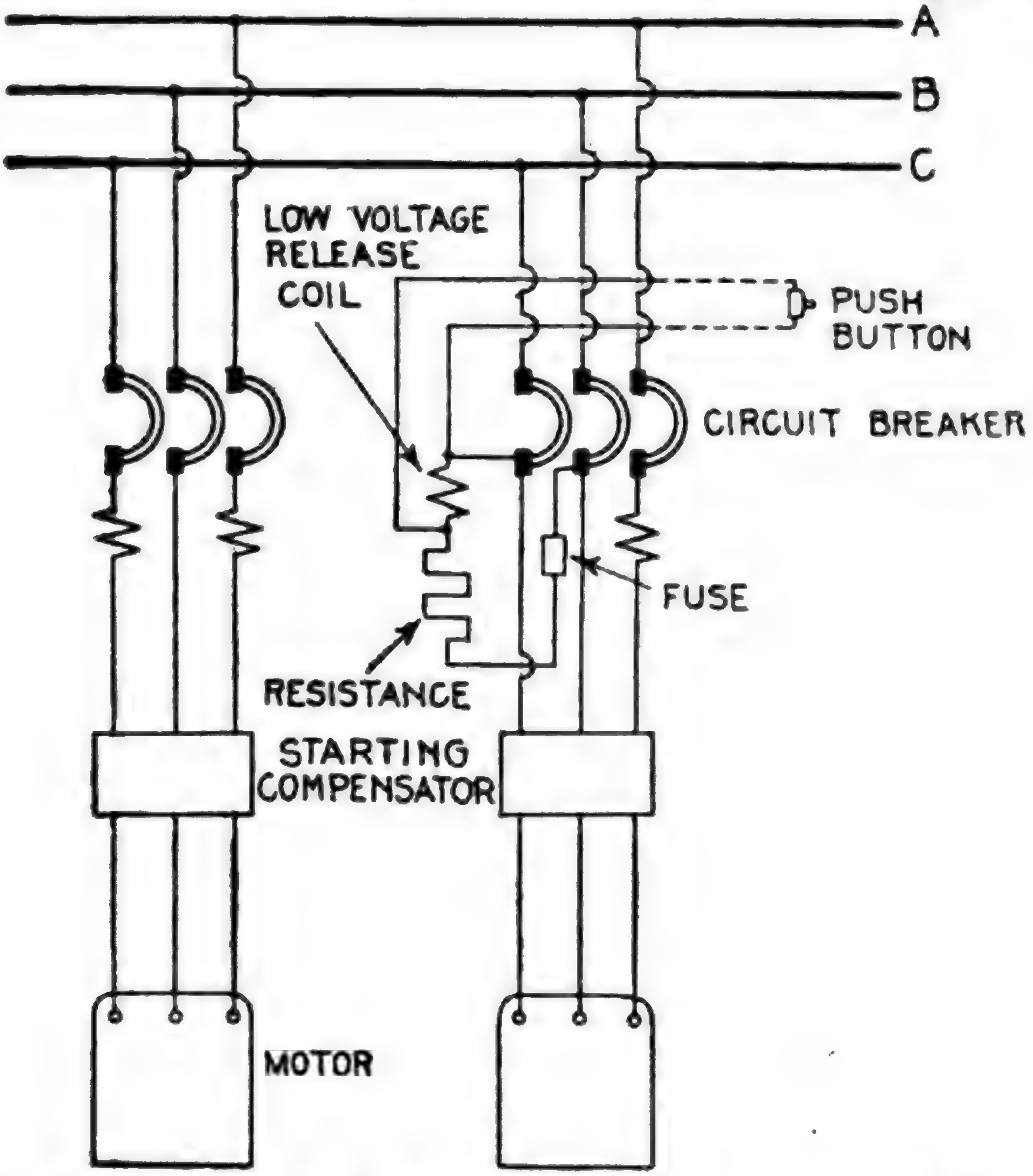

A
B
C
LOW VOLTAGE RELEASE COIL
PUSH BUTTON
CIRCUIT BREAKER
FUSE
RESISTANCE
STARTING COMPENSATOR
MOTOR

FIG. 2,281.—Diagram showing three phase motors protected by triple pole overload circuit breakers, with two overload coils, also one overload coil and low voltage release coil. The use of the low voltage release allows the breaker to be tripped from a distance by means of a short circuiting switch or push button.

A.C. and D.C. relays are respectively known as *circuit opening* and *circuit closing* relays, being later fully described.

Circuit Opening Relays.—The duty of a circuit opening **relay is** *to open the* **auxiliary circuit,** *usually alternating current,* *and thereby cause the oil switch or circuit breaker to be opened by the use of a trip coil in the secondary of a current transformer, or* by low *voltage release coil.*

The trip coil of the breaker is generally shunted by the relay contacts and when the moving contact of the relay disengages from the stationary contact, the current from the transformer which supplies the relay, flows through the trip coil thus opening the breaker. These features of operation are shown in fig. 2,282.

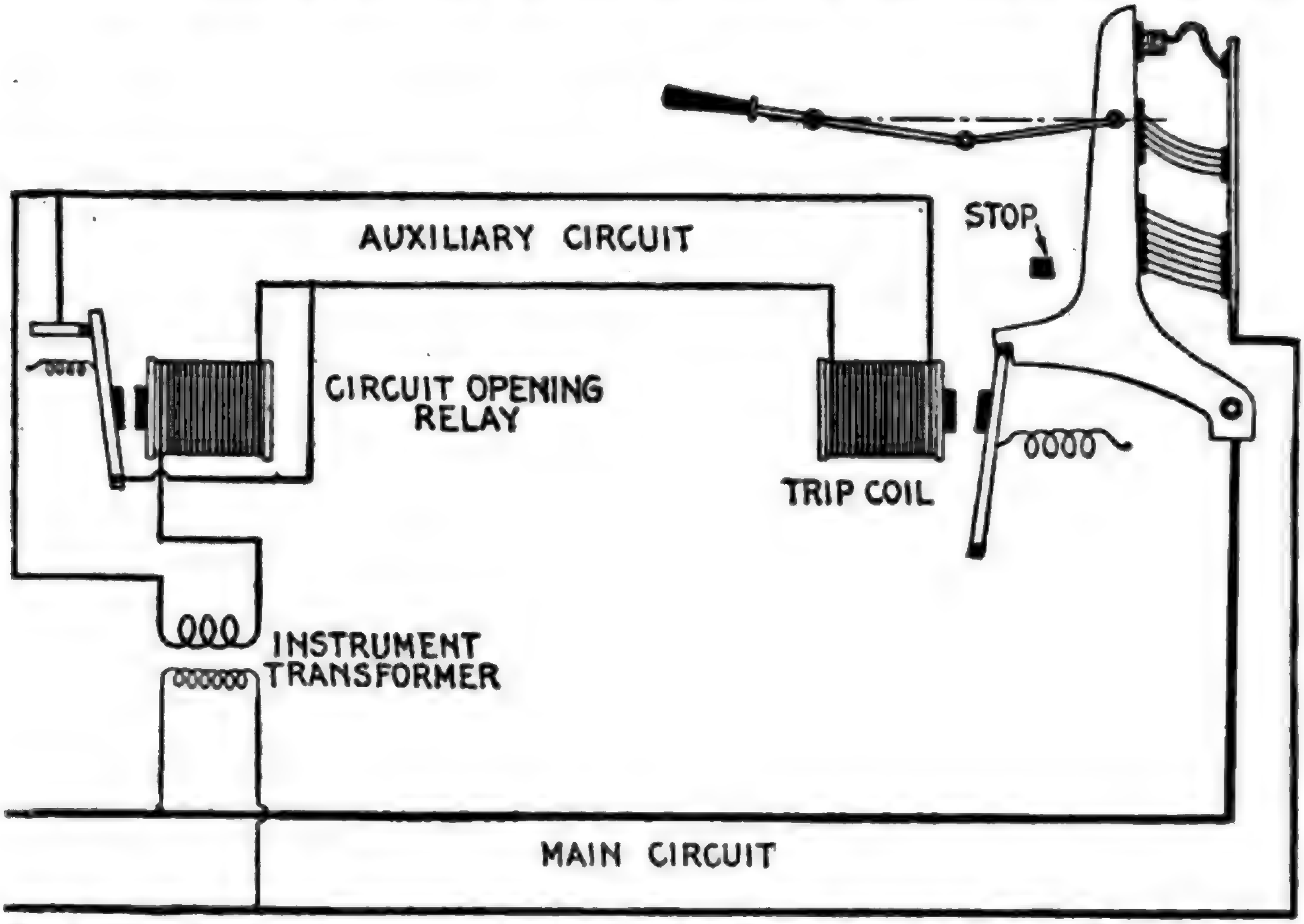


FIG. 2,282.—Diagram illustrating the operation of a **circuit opening relay**. When the relay contacts are in the normal closed position, as shown, the coil is short circuited. When the predetermined abnormal condition is reached in the main circuit, the relay contacts are opened with a quick break, sending the current through the trip coil momentarily, and opening the breaker.

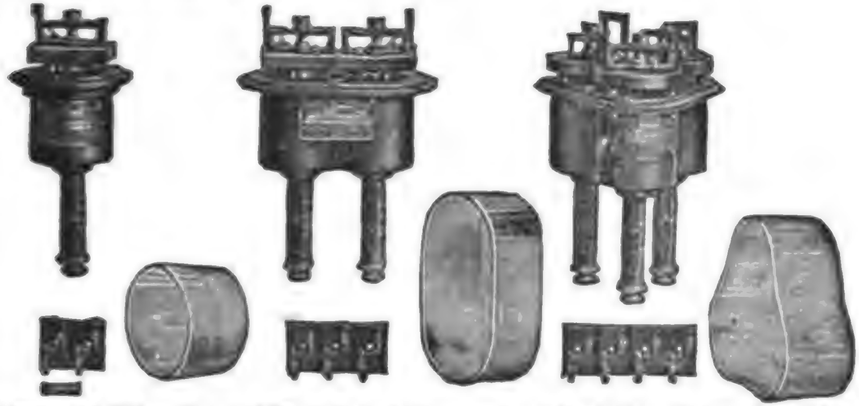
Ques. Where are circuit opening relays chiefly employed?

Ans. In places where direct current is not available for energizing the trip coil.

Ques. What is the objection to alternating current trip coils?

Ans. They have relatively high impedance and impose a heavy volt ampere load on the transformers.

Circuit Closing Relays.—The duty of a circuit closing relay is to close the auxiliary circuit at the time when the predetermined abnormal condition is reached in the primary circuit. The closing of the auxiliary circuit energizes the trip coil and opens the breaker.



FIGS. 2,283 to 2,291.—General Electric instantaneous overload **circuit opening** relays, covers removed. Circuit opening relays are used chiefly in those cases where direct current for the tripping circuit is not available. Alternating current trip coils have relatively high impedance and impose a heavy volt ampere load on the current transformers. To reduce this load during normal operation the circuit opening relay is frequently used and is usually necessary where instruments and meters are to be operated on the same current transformers as the trip coils if the greatest accuracy be required. The relay contacts in the normal, closed position, short circuits the trip coil. When the relay operates on overload or other abnormal condition the contacts are opened with a quick break, sending the current through the trip coil circuit momentarily and tripping the switch. With circuit opening relays, the trip coils of the oil switch must be set to trip somewhat lower than the setting of the relay. **In construction** the relay consists of a solenoid with iron frame forming the support for the relay; a central plunger or armature of special construction which is picked up or released by the magnetic action of the solenoid; a plunger rod which actuates the relay contacts, which are mounted on an insulated base usually above the soleniod; a tube or plate for the calibration marking and adjustment; covers of glass or metal to keep out dust; terminal boards with points corresponding to tagged leads from relay coils and external wiring diagrams. The relay contacts are of two kinds, circuit opening, as shown above, and circuit closing, as shown in figs. 2,292 to 2,300.

Ques. What kind of current is generally used for the auxiliary circuit of a circuit closing relay?

Ans. Direct current.

Ques. At what pressure?

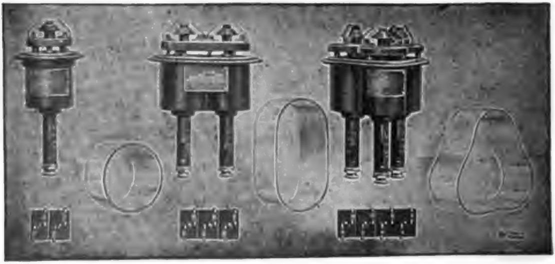
Ans. From 125 to 250 volts.

Ques. Where is this current usually obtained?

Ans. From a storage battery, or from the exciter.

Ques. For what current are the contacts ordinarily designed?

Ans. About 10 amperes.



FIGS. 2,292 to 2,300.—General Electric alternating current instantaneous overload **circuit closing** relays, covers removed. The function of a circuit closing relay is to close an electrical circuit, usually direct current, through a trip coil on an oil switch or circuit breaker, or it may short circuit a low voltage release coil, and thereby open the oil switch of circuit breaker on occurrence of the condition upon which the relay is designed to operate. Direct current at 125 or 250 volts taken from exciter bus bars or storage battery system is generally used for the tripping circuit. Circuit closing contacts have a cone shaped central element of carbon or metal which makes contact with flexible contact fingers symmetrically arranged above the cone. These contacts will make and break a circuit of 10 amperes at 125 volts without the use of auxiliary circuit opening switches. Relays are made with two or three contacts for connecting one side of a direct current circuit through one or two separate circuits, or trip coils respectively, to the side of opposite polarity. Usually only two contacts are required. Where two or more trip coils are used, which may not be connected permanently in parallel, the three contact relays are selected and in some cases four contacts furnished.

Primary and Secondary Relays.—Primary relays are sometimes called series, relays as they have the current coils connected directly in series with the line, both on high and low tension circuits.

Secondary relays receive their current supply from the secondary circuits of current transformers. Alternating current relays connected to secondary of pressure transformers and relays with both current and pressure windings are included in this class.

Ques. What is the usual winding of the coils?

Ans. The current coils are usually wound for 5 amperes and the pressure coils for 110 volts.

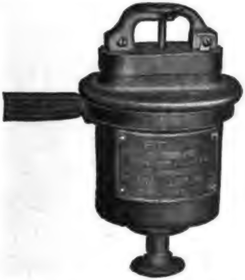


FIG. 2,301.—Alternating current low voltage circuit closing low voltage relay, for 600 volts or less. The contacts are similar to those of the circuit closing overload type except that they are inverted. As long as the pressure is normal the contact cone is held above the contacts. When the pressure falls below one half normal, the cone and plunger rod drop and close the contact. This relay does not pick up its own plunger. The plunger rod is pushed up by hand after the pressure circuit is established. Low voltage relays are generally used in connection with a low voltage release or shunt trip coil on an oil switch or a circuit breaker. They are used in connection with motor booster sets to prevent a disastrous speed of the booster which might result from the loss of alternating current power. They are also sometimes used for indicating purposes.

Ques. What refinement is made in the design of relays and why?

Ans. Care is exercised to reduce to a minimum the volt ampere load imposed by the relay on the current transformer to permit the use of unstranded meters and relays upon the same transformer.

The use of circuit opening relays to cut out the trip coil of an oil switch during normal operation, has been described, and in the short time that the trip coil is in circuit, it does not affect the accuracy of the instrument readings. This practice, however, does not apply in th case of curve drawing meters, voltage compensators or other devices which have in themselves sufficient load for separate current transformers. In this connection it should be noted that to obtain accurate

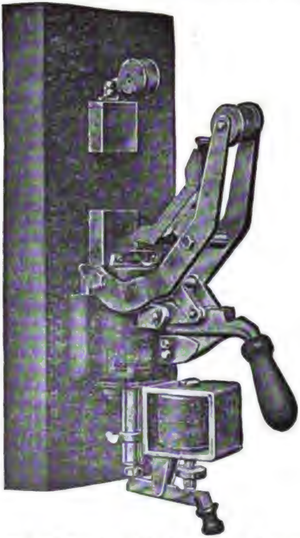


FIG. 2,302.—Condit type K circuit breaker with shunt trip and no voltage attachment. Th **shunt trip** is usually applied as an auxiliary to other types of trip. It consists of a fine wir coil which is mounted as a self-contained part of the breaker and which when energized trips the circuit breaker. It is used to open the breaker from some distant point, and th coil is arranged to be connected across the line. The coils are so arranged that the circu breakers will operate on a voltage 25% above or 25% below normal. The shunt trip co is not intended to remain across the line and should be only momentarily energized. Th **no voltage trip**, receives energy from a high resistance or fine wire coil which is arranged t be placed directly across the line, but in contradistinction to the shunt trip type, in which th coil is *momentarily* energized to trip the breaker, the no voltage coil is *constantly* energize and a *decrease* or failure of pressure trips the breaker. It can be used as a remote contro device the same as the shunt trip. Its general use, however, is to cause the circuit breake to open when the voltage of the line fails from any cause. Its use is recommeded on al motor circuits, as it affords an additional protection against accidents, for if the voltag should fail, the breaker immediately opens, and before the machine can start again th attendant must close the breaker. It will not work for the protection of storage batteri or of motor generator sets charging storage batteries, as, when the voltage of the generato fails, the voltage of the battery still maintains its full value. The action of the coil is independent of the direction of flow of current; it simply allows the breaker to stay closed a long as the voltage is on the line and opens the breaker when the voltage on the line ceases. No voltage circuit breakers are normally so adjusted that they will not release until th voltage approaches 50% of normal.

instrument and meter readings; the current transformers should not be loaded beyond certain limits which depend upon the volt ampere load and power factor of each of the connected devices.

So great is the variety of combination used and the variations of these factors in their several combinations at different loads and settings, that special consideration of each arrangement is advisable.

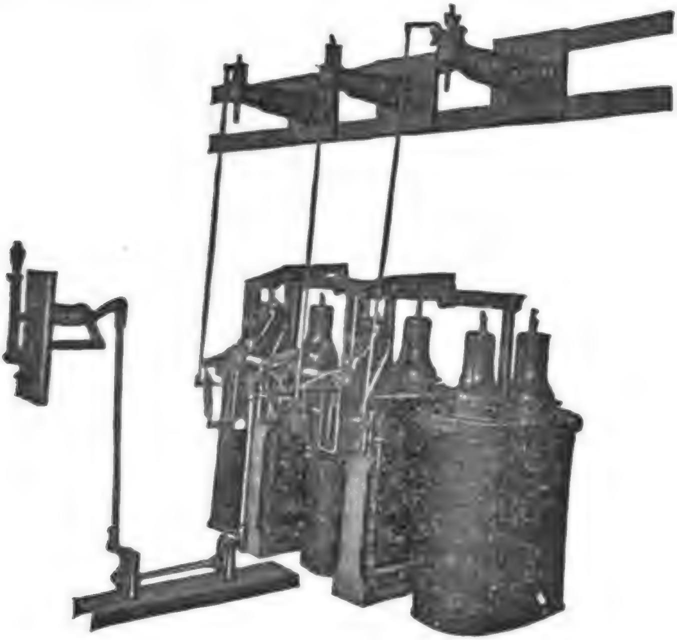
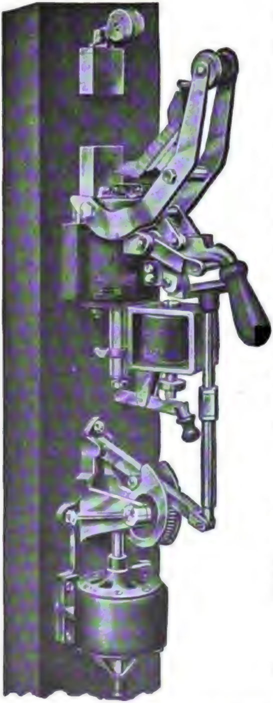


Fig. 2,303.—General Electric alternating current **high pressure** series overload **relays** controlling 45,000 volt oil switches. These relays are connected in series with the line. If current transformers are to be used on the same circuit for other purposes, and have sufficient capacity to supply energy for operating relay coils, then secondary relays would be more economical, otherwise the series relays are much less expensive. By means of a specially treated wooden rod, the relay operates a tripping switch, closing a separate tripping circuit, usually 125 or 250 volts direct current. Relays and switches are for mounting on flat surfaces. Series relays are essentially the same as secondary relays except in the coil winding and insulation. The corrugated horizontal arms which carry the relays, as shown, are insulated posts, insulating the relays from the ground. The wood rod from each relay is connected directly to a tripping shaft on the oil switch which buckles an auxiliary toggle, thereby opening the main toggle and tripping the oil switch.

Overload Relays.—Series relays are connected directly in series with the line and are chiefly used with high pressure oil break switches for overload protection. If current transformers are to be used on the same circuits for other purposes, and have sufficient capacity to admit of adding a relay coil, secondary



relays would be more economical; otherwise, the series relays are less expensive.

By means of a specially treated wooden rod, the relay operates a tripping switch, closing a separate tripping circuit, usually 125 or 250 volts direct current. Series relays are essentially the same as secondary relays except in the coil winding and insulation.

Underload Relays.—These are similar in construction to low voltage relays but have current instead of pressure windings.

Over Voltage Relays.—These are usually of the circuit closing type and are similar to secondary overload relays, but have pressure instead of current windings.

Low Voltage Relays.—Relays of this class are in most cases used

FIG. 2,304.—Condit 600 volt, 1,500 ampere single pole back connected type K circuit breaker, **motor operated.** The mechanical and electrical features of the circuit breakers are no different than when hand operated, the only difference being that the motor is used for the operating means. This motor is so arranged that even should it over travel, due to an accident to the controlling circuit, it cannot produce more than a pre-determined strain on the circuit breaker. In other words, after the motor has closed the circuit breaker, further travel of the motor will not result in putting a strain on the operating parts. Suitable motors are supplied for this service, the type of motor varying in accordance with the character of the operating current supplied. The advantage of this type of electrical operation is that it puts very little strain on the switch mechanism, takes very little operating current, allows the use of standard parts, and makes an extremely substantial and flexible structure. Its disadvantage is that it closes slowly, and it must not, therefore, be used in places where quick closing is essential.

for the protection of motors in the event of a temporary weakening or failure of the pressure. They are also used in connection with a low voltage release or shunt trip coil on an oil switch or a circuit breaker.

Reverse Energy Relays.—The chief object of this species of relay is to protect the generator. When so used, the overload adjustment is set at the maximum value to give overload protection only at the maximum carrying capacity of the generator and a sensitive reverse protection to prevent a return of energy from the line.

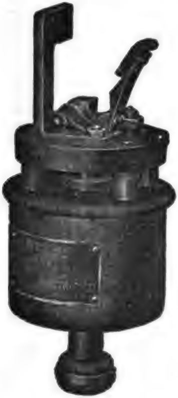


Fig. 2,305.—General Electric direct current solenoid control relay. Solenoids for operating large switches, etc., frequently require comparatively large operating currents in the "closing" coils. This necessitates the use of relatively heavy leads between the control switch and the solenoid and is the cause of severe arcing at the control switch, especially with solenoids of high inductance. These objectionable features can best be eliminated by the use of a suitable control relay located near the solenoids. The control relay consists of a solenoid plunger and switch, the latter insulated from the frame of the relay. It operates satisfactorily on one-half the rated voltage and requires only a very small operating current. The terminals of the switch and the relay coils are independent. The relay can be wound for operation on 125, 250, or 600 volt circuits.

Reverse Phase Relays.—This type of relay is used chiefly to prevent damage in case of reversal of leads in re-connecting wiring to two or three phase motors.

Time Element.—It is often inconvenient that a circuit breaker should be opened immediately on the occurrence of what may prove to be merely a momentary overload, so that time lag attachments are frequently provided, particularly with relays. These devices, which may form part of the relay or may be quite distinct from it, retard its action until the overload has lasted for a pre-determined time—several seconds or more.

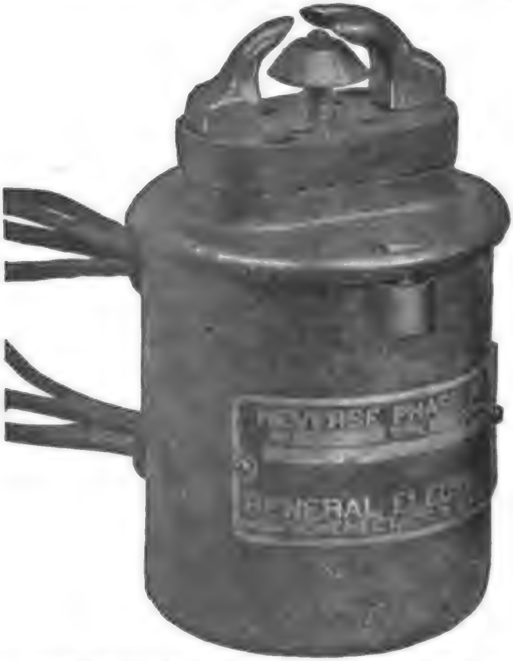


FIG. 2,306.—Alternating current series reverse phase single pole, circuit closing, two contac relay for 600 volts or less. This type of relay is used chiefly to open motor circuits fo elevators to prevent damage in case of reversal of leads in reconnecting wiring to tw or three phase motors. The relay is provided with a dust proof metal cover.

Ques. What should preferably govern the time lag?

Ans. It should depend on the extent to which the overload is reduced as the time elapses.

Instantaneous Relays.—The so called instantaneous relays operate almost instantly on the occurrence of the abnormal condition that they are to control.

There is of course a slight time element comparable with that of an overload circuit breaker, but for practical purposes, the operation may be considered as instantaneous.

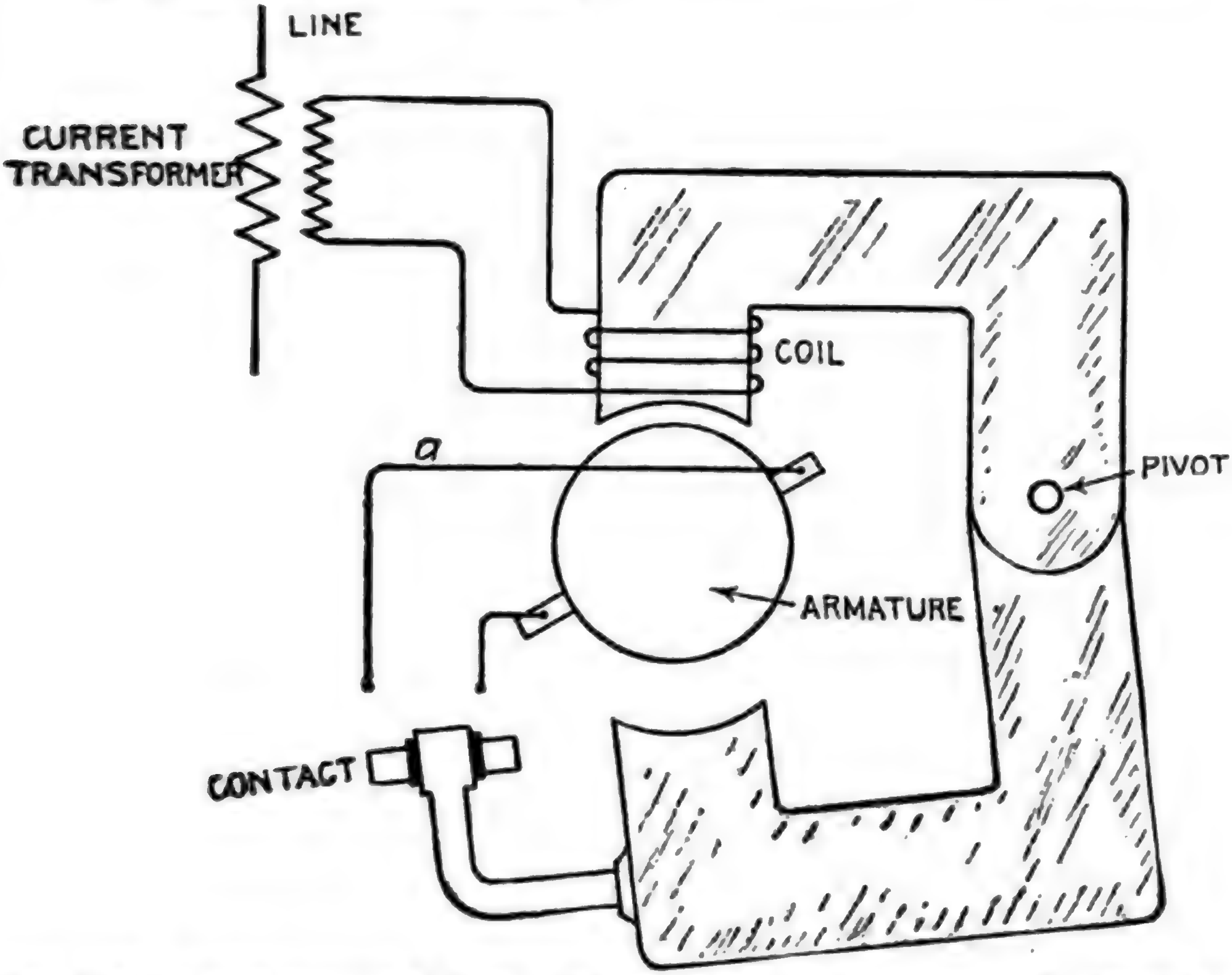


FIG. 2,307.—Electric circuits of Condit type "A" relay. The construction is described in fig. 2,309. As here shown, the relay is not in operation, but should the current passing through the coil be of sufficient value to cause the lower movable half of the magnetic circuit to approach the upper stationary half of the circuit, *the relay will be transformed from an ordinary* **electromagnet** *into a* **repulsion motor.** The contact will short circuit the brushes of the armature and thus cause it to revolve, the speed of rotation being dependent on the amount of current flowing to a predetermined point, and thereafter the speed of rotation of the motor remains constant irrespective of the current value. **Time adjustment:** This is obtained by varying the distance through which the contact travels, provision being made whereby adjustment can be made as close as .1 of a second. **Current adjustment:** This is obtained by means of a calibrated spring. Standard relays are calibrated at 6, 8, 10, and 12 amperes, the coils being designed to carry five amperes continuously, with a temperature rise not exceeding 86° Fahr. **Power to operate relay:** The relay requires twenty volt amperes for its operation at full load; the influence of this type of relay on the ratio and phase angle of current transformers is small.

Time Limit Relays.—Under this classification there are two sub-divisions.

1. Definite time limit;
2. Inverse time limit.

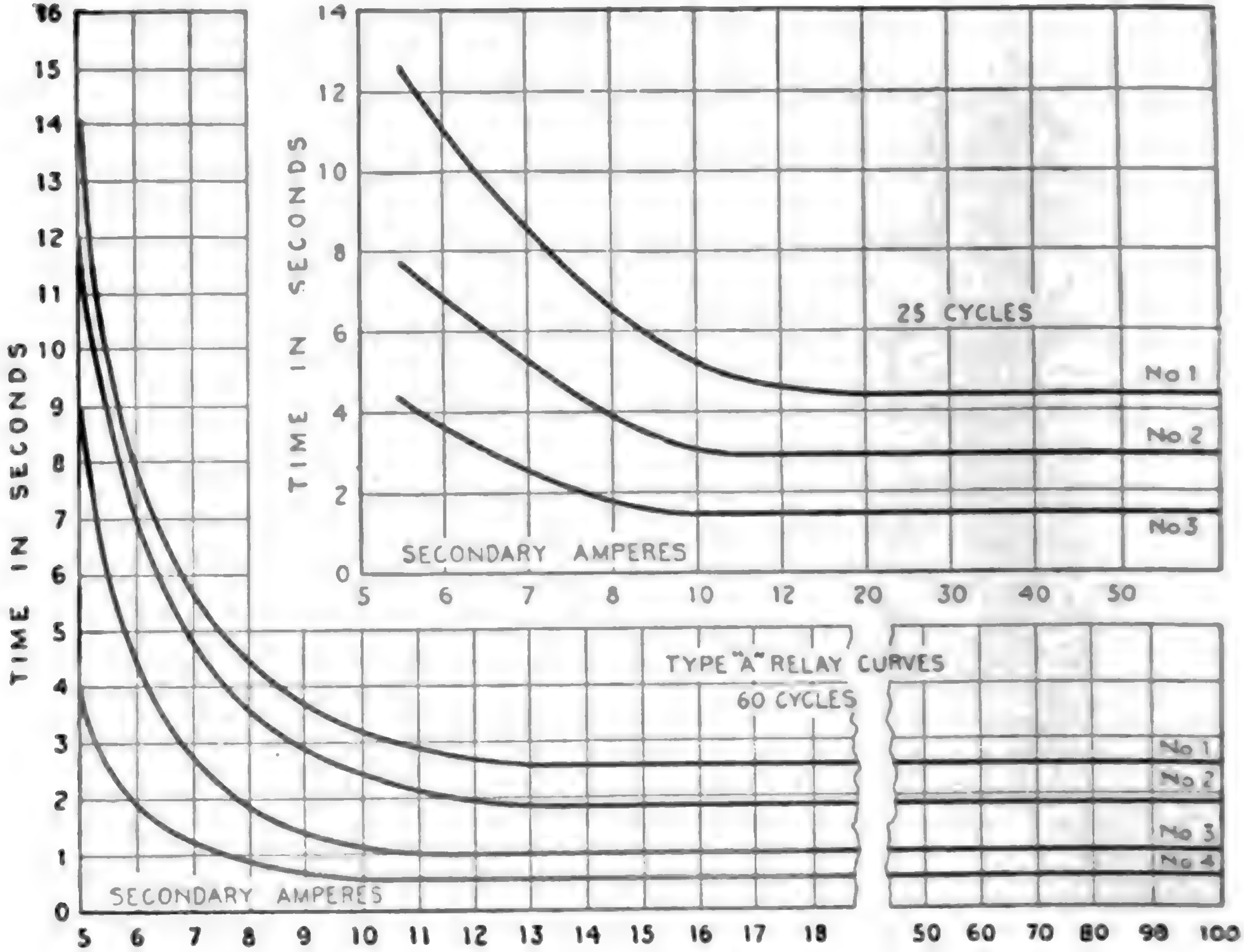


FIG. 2,308.—Characteristic curves of Condit type A selective relay. Curves 1, 2, 3, and 4 show the time variation of this relay with different settings at the various current values. The relay may be adjusted to trip the switch at any point represented between curves 1 and 4. This relay is a combination of an *inverse time limit* relay and a *definite time limit* relay. The combination of the characteristics of the two types are seen in the curve, the first part of which is **inverse,** and the latter part **definite** from a point of three or four times full load current. This combination of features being desirable as, for instance, in transmission work, particularly where it is necessary to use circuit breakers set selectively, as, due to the inverse feature of the curve, the relays can be set so that on a moderate overload, they will require the proper length of time to operate, and at the same time will operate quickly enough on heavy short circuits to prevent damage to the distribution system or its apparatus. Due to the definite feature of the latter part of the curve, the relays of the varying circuit breakers when once set to operate at different time values will never operate simultaneously irrespective of the value of the short circuit current, thus tending toward continuity of service.

Ques. Describe the time mechanism of a definite time limit relay.

Ans. It consists of an air dash pot, and an air diaphragm or equivalent retarding device connected to the contact mechanism.

Ques. How does it operate?

Ans. In some designs, when the contacts are released, they descend by gravity against the action of the retarding device thereby making contact a definite interval after the occurrence of the abnormal condition.

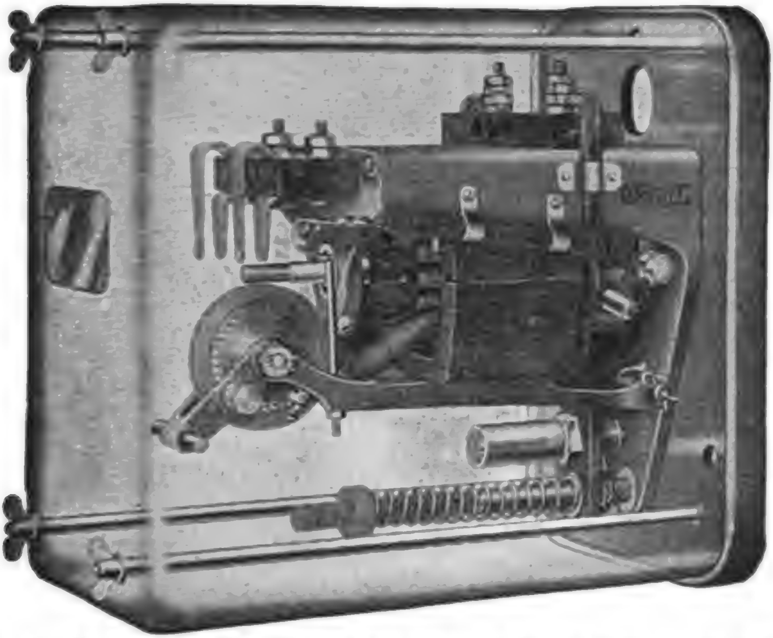


FIG. 2,309.—Condit type "A" **selective relay,** designed for use with circuit breakers where selective or discriminating action is required. The circuits and connections of this relay are illustrated in fig. 2,307, and its characteristics in fig. 2,308. **In construction,** the relay consists of *a special motor with a short circuited armature and a split field.* **Under normal conditions,** the fields are separated from each other and the motor armature does not revolve. The force tending to pull the two faces of the field together is opposed by a spring, the compression of which determines the number of amperes necessary to cause the relay to begin operation. The motor structure performs the whole work and the motor itself unmeshes and meshes the gears without the aid of any external device.

Ques. How does the inverse time limit type operate?

Ans. The actuating and contact mechanism is attached directly to an air bellows and in operation tends to compress the bellows against the action of a specially constructed escape valve in the latter.

Ques. Why is the arrangement called *inverse* time limit?

Ans. Because the retardation varies inversely with the

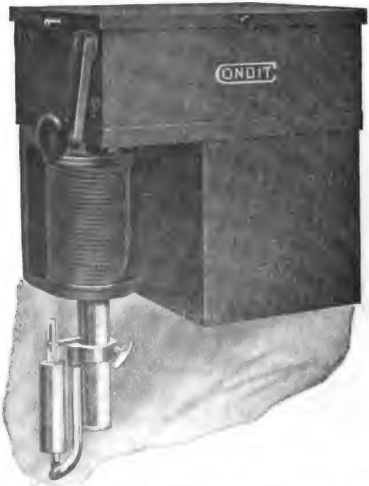


Fig. 2,310.—Condit type "B" **time limit attachment**, designed to give sufficient time to allow an induction motor to start without opening the circuit breaker, and not have the circuit breaker trip on the momentary rush of current. **Its action is inverse; that is,** ***the greater the current the less time it takes to operate*** and is so arranged that four to five times full load current or a short circuit will trip the circuit breaker instantly. The time limit attachment is applied directly to the armature which trips the circuit breaker and is adapted for the so called primary trip. It consists of an air vacuum dash pot with a graphite piston, the dash pot being fastened to the stationary calibrating ring of the trip coil and the moving outside cylinder is fastened to the armature of the circuit breaker. When the current reaches a point where it overcomes the weight of the armature and lifts the same, the magnetic force tending to raise the armature is opposed by the vacuum created in the interior of the cylinder. As the magnetic force continues, the vacuum is overcome due to the leakage of air past the plunger and the armature gradually moves up until it reaches the point where it trips the circuit breaker. If at any point of the armature travel, the current drop back to normal, the armature immediately resets itself by means of a ball valve in the top of the brass cylinder pressure on the bellows, and therefore inversely with the magnitude of the abnormal condition.

Ques. What other device may be used to retard the operation?

Ans. A damping magnet is sometimes used which acts on a disc or drum and which may be adjustable.

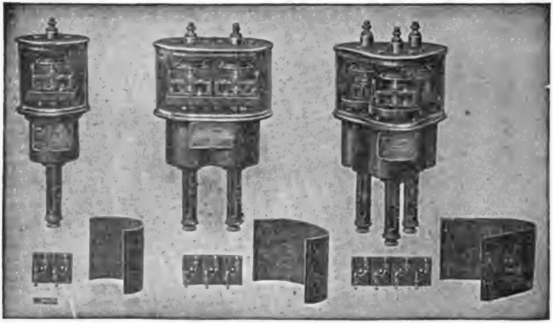
FIGS. 2,311 and 2,312.—General Electric alternating current **low pressure** series overload relays. Fig. 2,311, instantaneous time limit relay; fig. 2,312, inverse time limit relay. These relays have carbon contacts and will make or break a direct current circuit of 10 amperes at 125 volts without auxiliary circuit opening switch. They are used where several circuits are controlled by one automatic oil break switch or one shunt trip, overload and shunt trip or low voltage release carbon break circuit breaker. These relays may be used for signal purposes; they are back connected, the connections can be seen in the illustrations.

Ques. How is the inverse time element introduced by this arrangement?

Ans. The retardation is due to eddy currents induced by moving the disc or drum through the magnetic field. The reaction thus induced varies inversely with the magnitude of the force with which the disc or drum is urged through the fiel and hence inversely with the abnormal condition.

Ques. What are the ordinary limits of adjustment for inverse time limit relays?

Ans. From one-half second to 30 seconds, depending upo the time setting and magnitude of the overload current.



FIGS. 2.313 to 2,321.—General Electric time limit overload circuit opening relays with cove removed. The construction of this relay is similar to that of the inverse time limit rela except that it has a compression spring interposed between the plunger and diaphrag The plunger compresses the spring and further motion is prevented by a stop, mak the relay practically independent of the amount of the overload, only the stored ener of the spring, if the overload continue, applies power, dependent on its own mechanic strength, to the diaphragm. The time limit therefore becomes practically a consta for any given setting under ordinary conditions of overload or short circuit. If, however, the overload come on slowly so that the spring is not fully compressed at once, th time limit will vary slightly. If the scheme of selective operation make it necessary t take care of a creeping load of this character, two relays may be used and definite ti limit positively secured. In this case, an instantaneous circuit closing, overload rela would be used and a definite time limit relay, provided with a direct current coil in circuit with the closing contacts of the first relay. The time limit relay would be of the circuit closing type and control a direct current trip coil on the oil switch.

A setting of from two to six seconds is ordinarily used, depending upon the requirements. Where selective operation is desired a minimum setting of two seconds is recommended.

Differential Relays.—In this type of relay there are two electromagnets. In normal working these oppose and neutralize each other. Should, however, either winding become stronger or weaker than the other, the balance is upset, the magnet energized, and the relay comes into operation.

A modification of such a relay for alternating current is shown in fig. 2,322, from which it will be seen that when the currents are as indicated, the circuit A has the larger pressure induced in it, whereas, should the main current reverse with reference to the shunt current, the circuit B would have the larger induced pressure.

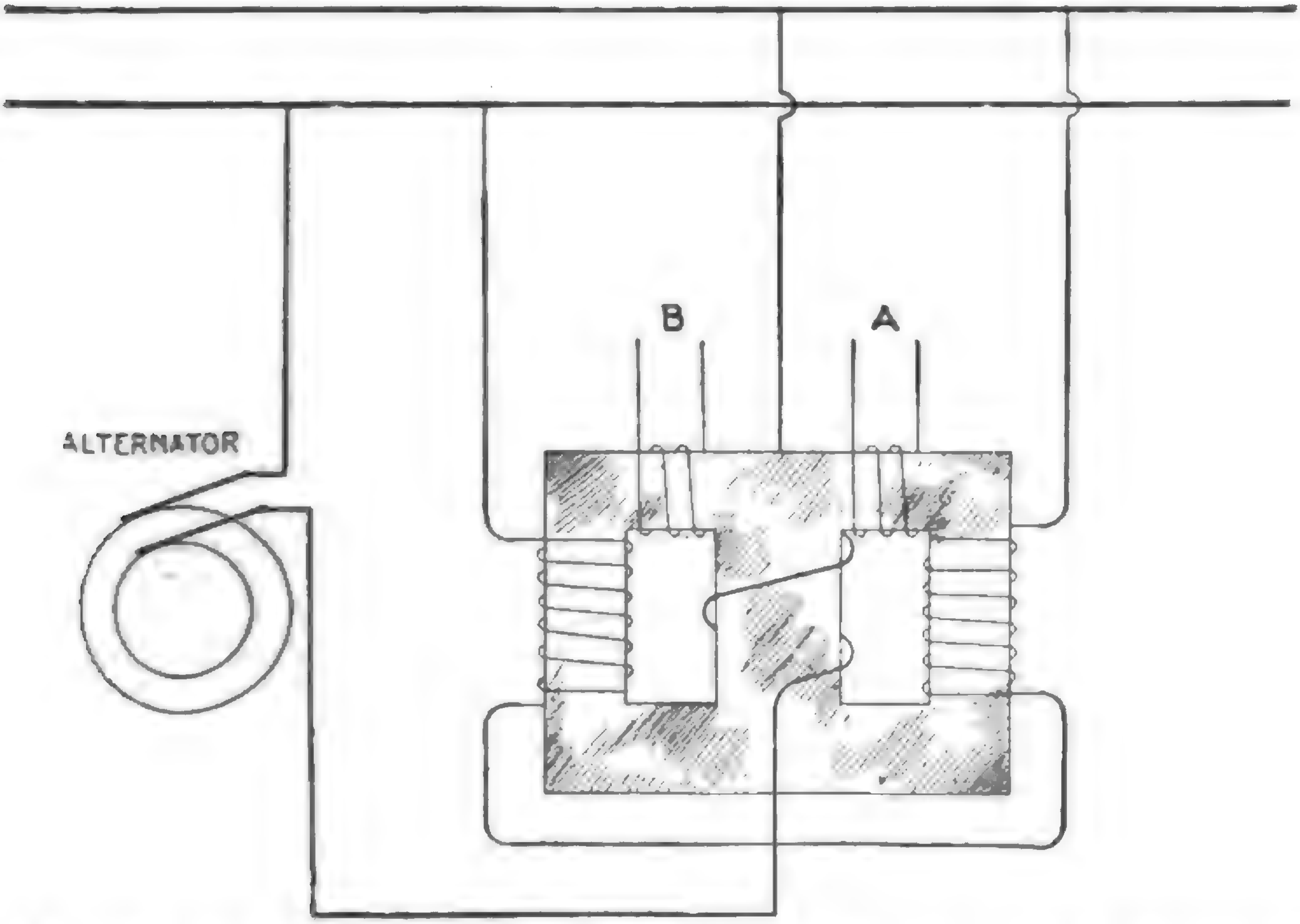
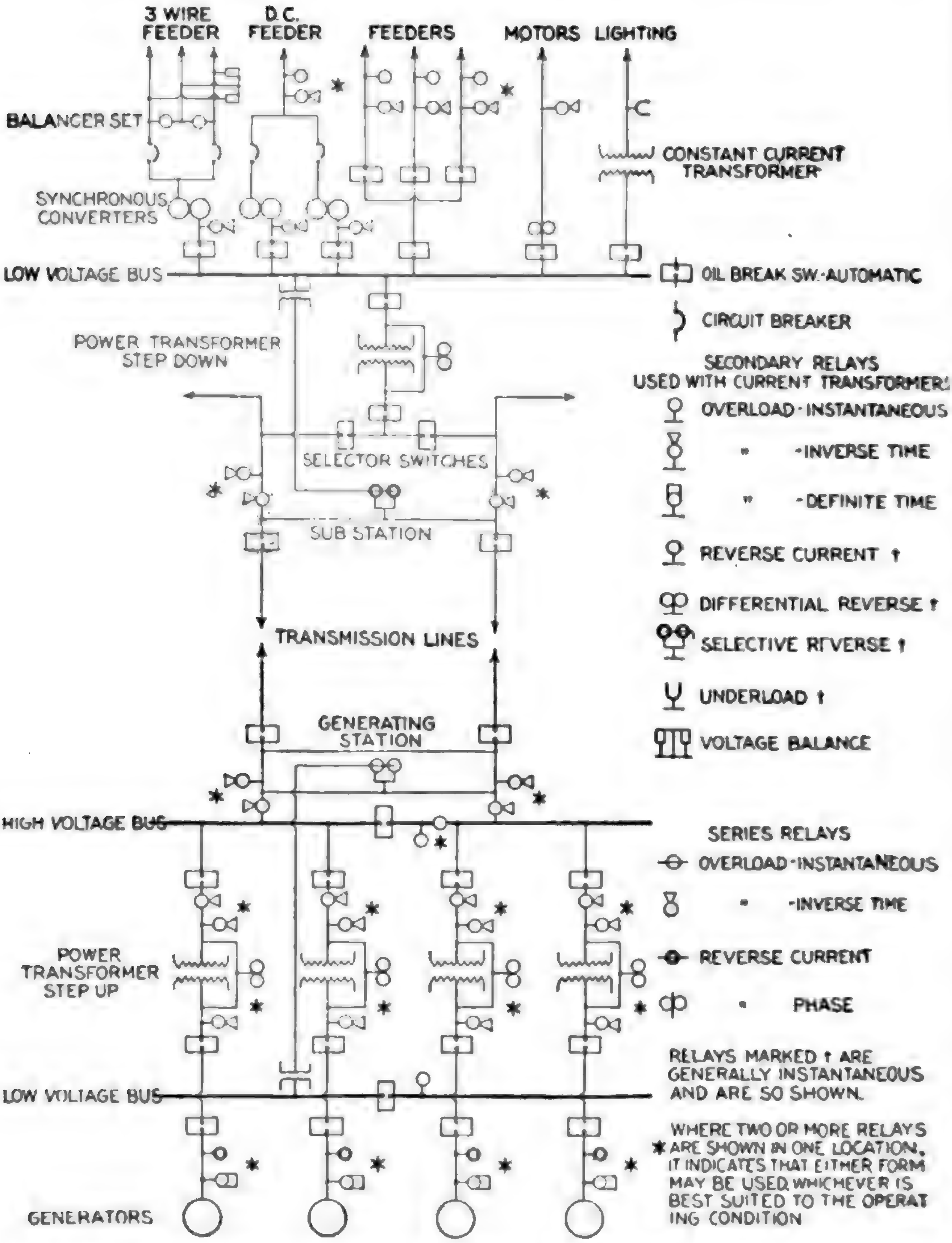


FIG. 2,322.—Differential relay transformer and reverse current circuit breaker discriminating device. A differential relay is *one whose electromagnet has two windings.* **In normal working** *these oppose and neutralize one another.* Should, however, either winding become stronger or weaker than the other, the balance is upset, the magnet is energized, and the relay comes into operation. A modification of such a relay for alternating current is here shown, from which it will be seen that when the currents are as indicated, the circuit A has the larger pressure induced in it, whereas, should the main current reverse with reference to the shunt current, the circuit B would have the larger induced pressure.


3 WIRE FEEDER
D.C. FEEDER
FEEDERS
MOTORS
LIGHTING
BALANCER SET
CONSTANT CURRENT TRANSFORMER
SYNCHRONOUS CONVERTERS
LOW VOLTAGE BUS
POWER TRANSFORMER STEP DOWN
SELECTOR SWITCHES
SUB STATION
TRANSMISSION LINES
GENERATING STATION
HIGH VOLTAGE BUS
POWER TRANSFORMER STEP UP
LOW VOLTAGE BUS
GENERATORS
OIL BREAK SW.-AUTOMATIC
CIRCUIT BREAKER
SECONDARY RELAYS USED WITH CURRENT TRANSFORMERS
OVERLOAD-INSTANTANEOUS
" -INVERSE TIME
" -DEFINITE TIME
REVERSE CURRENT †
DIFFERENTIAL REVERSE †
SELECTIVE REVERSE †
UNDERLOAD †
VOLTAGE BALANCE
SERIES RELAYS
OVERLOAD-INSTANTANEOUS
" -INVERSE TIME
REVERSE CURRENT
" PHASE
*

RELAYS MARKED † ARE GENERALLY INSTANTANEOUS AND ARE SO SHOWN.

* WHERE TWO OR MORE RELAYS ARE SHOWN IN ONE LOCATION, IT INDICATES THAT EITHER FORM MAY BE USED WHICHEVER IS BEST SUITED TO THE OPERATING CONDITION.

FIG. 2,323.—Diagram of modern power house wiring and busses showing location of relays.

***How to Select Relays.**—The following general information on relays, together with reference to the one line diagram, fig. 2,323, will be of interest and assistance in making a selection from the various relays previously described to meet the requirements of modern power house and sub-station layouts.

Single pole relays are used on single phase and on balanced three phase circuits.

Double pole relays are used on ungrounded three phase and on quarter phase.

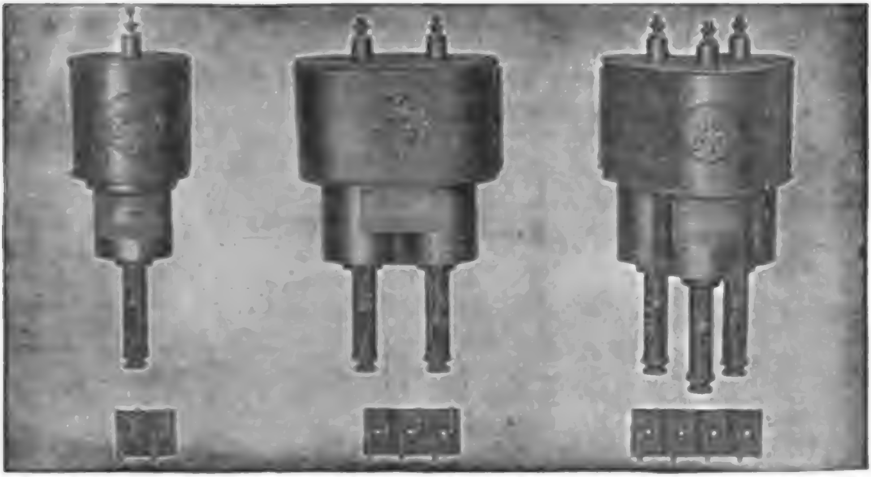


FIG. 2,324 to 2,329.—General Electric inverse time limit overload circuit closing relays. In this type of relay its mechanism is so designed that a delay or lapse of time in opening the circuit breaker after a pre-determined condition of the circuit has been reached, depends on the flow of current, that is, if the current be great, the time will be small, and if the current be of a moderate value, the time will be correspondingly longer.

Triple pole relays are used on three phase grounded neutral and interconnected quarterphase.

Circuit closing relays are recommended in all cases where a constant source of direct current is available for operating trip coils.

The conditions for which relays have been designed for power circuits may perhaps be best described, by considering a one line diagram from the generator end to the sub-station auxiliary machines and feeders.

Considering first alternating current circuits, the prevailing practice is to make the circuit breakers by which the alternators are connected to the low tension bus *non-automatic*, in order to insure minimum interruption of alternator service. The chance of trouble in this part of the circuit is remote, but should it occur, the station attendant coul generally open the circuit breaker before the machines would be injure

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*NOTE.—As suggested by the General Electric Co.

Reverse current relays of instantaneous or time limit types a often connected to the secondaries of current and of pressure tran formers to indicate by lamp or bell any trouble that may occur in th generator circuit.

These relays operate with a low current reversal at full pressure an conversely with a proportionally greater current at voltages less th normal. At zero pressure, the relay would act as an overload one, s for high overload. At zero current, a voltage considerably in excess normal would be required to operate it.

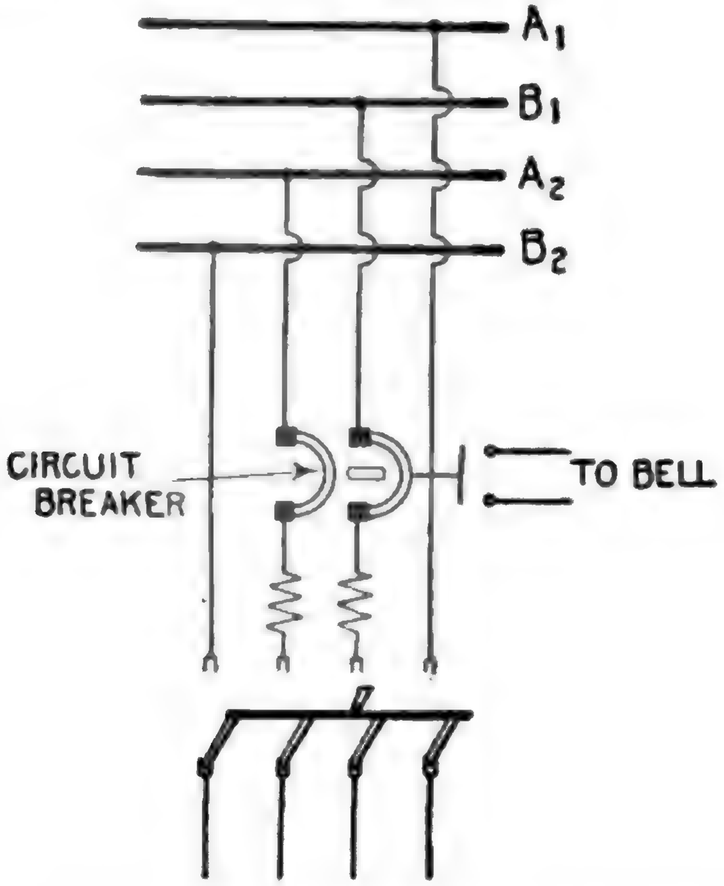


FIG. 2,330.—Diagram showing two phase motor or feeder circuit protected by double po double coil, overload circuit breaker (or two single pole breakers interlocked) with be alarm switch.

Specifications sometimes call for automatic generator circui breakers: in this case *definite time limit overload relays* are used. They are connected in the secondaries of current transformers and are designed to give the same time delay for all trouble conditions; they allow the defective circuit to be opened, i possible, at a point more remote from the generator than th generator circuit breaker.

When the total generator capacity exceeds the rated rupturing capacity of the circuit breakers, one or more sectionalizing circuit breakers are placed in each bus.

If operating conditions admit, these devices are made non-automatic and are left disconnected except in case of emergency; but if it be necessary for them to be continually in service, they may be made automatic by *means of instantaneous overload relays* connected to current transformers in the low voltage bus; the relays being adjusted to trip the circuit breaker under short circuit conditions, confining the trouble to one section and preventing the circuit breakers rupturing more than their rated capacity.

Installations with but *one bank of power transformers*, and without high voltage bus, are provided with automatic circuit breakers operated by an *inverse time limit relay*.

The relay is connected to the secondaries of current transformers, which in turn are connected in the low voltage side of the power transformer.

Stations with *more than one bank of power transformers*, a high voltage bus, and high and low voltage circuit breakers, may have both circuit breakers arranged to trip at the same time or one after the other. As in the former case, they are operated from the inverse time limit relay connected in the low voltage side.

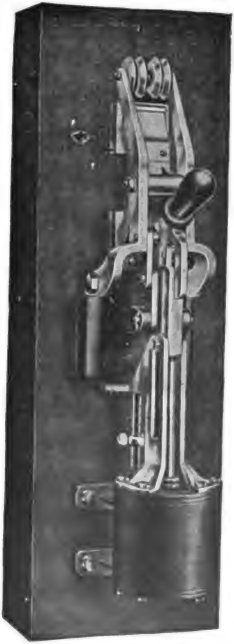
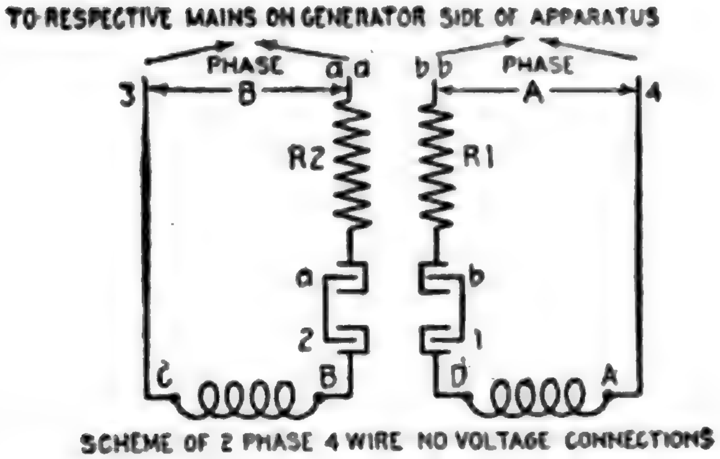
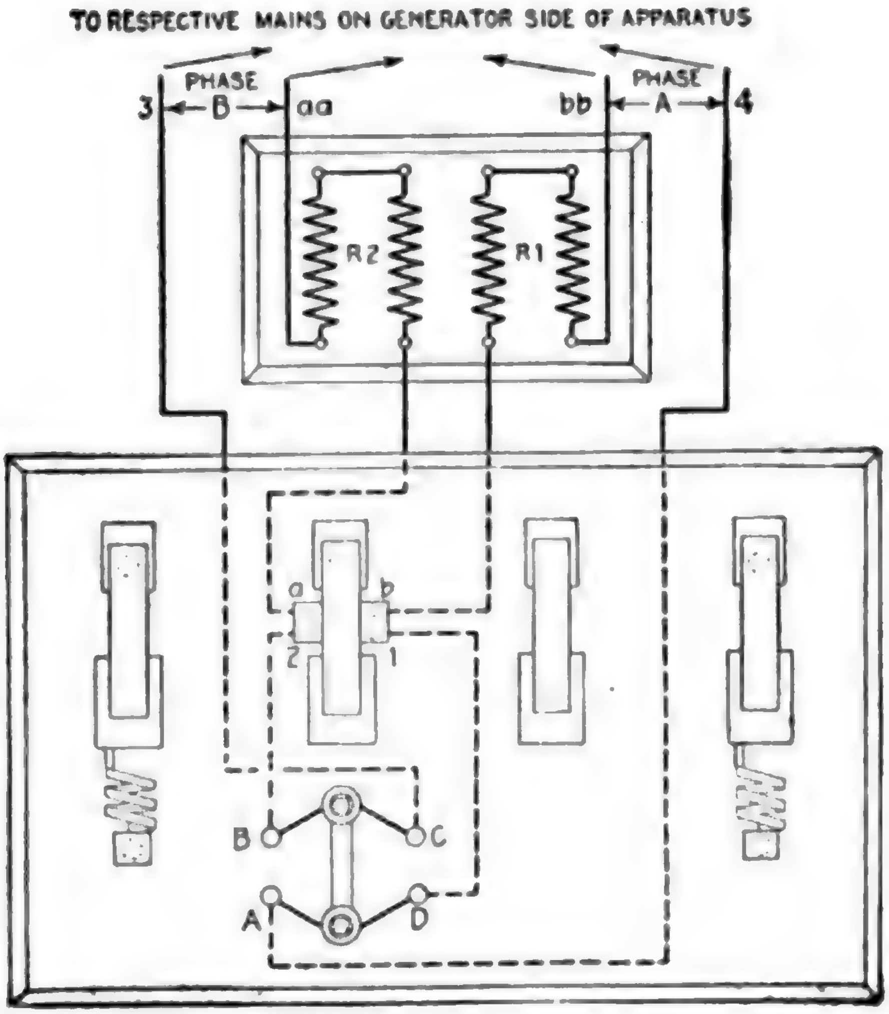
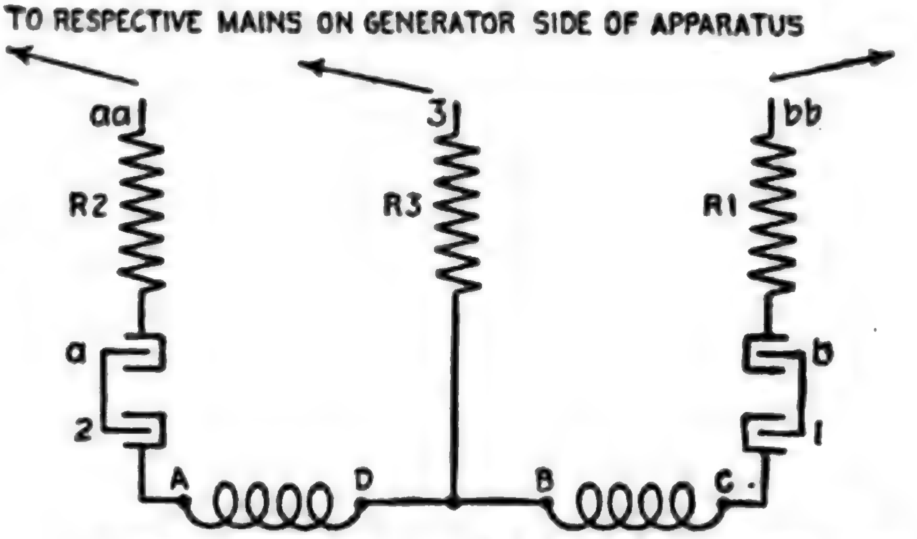


FIG. 2,331.—Condit 600 volt, 1,500 ampere, single pole type K circuit breaker **pneumatically operated.** It is the same as the electrically operated circuit breaker, except that a pneumatic cylinder mechanism is supplied in place of either the electromagnet or the motor. This cylinder mechanism is so arranged that the air pressure is only on the cylinder at the instant of operation. At all other times the air pressure is shut off by means of a control valve. The kind of remote control to be used depends on local conditions. In general, the hand operated remote control device is preferable where conditions are such that it can be used, and where it is necessary to use electrically operated, the motor operated type is recommended if conditions be such that slow closing is not objectionable.

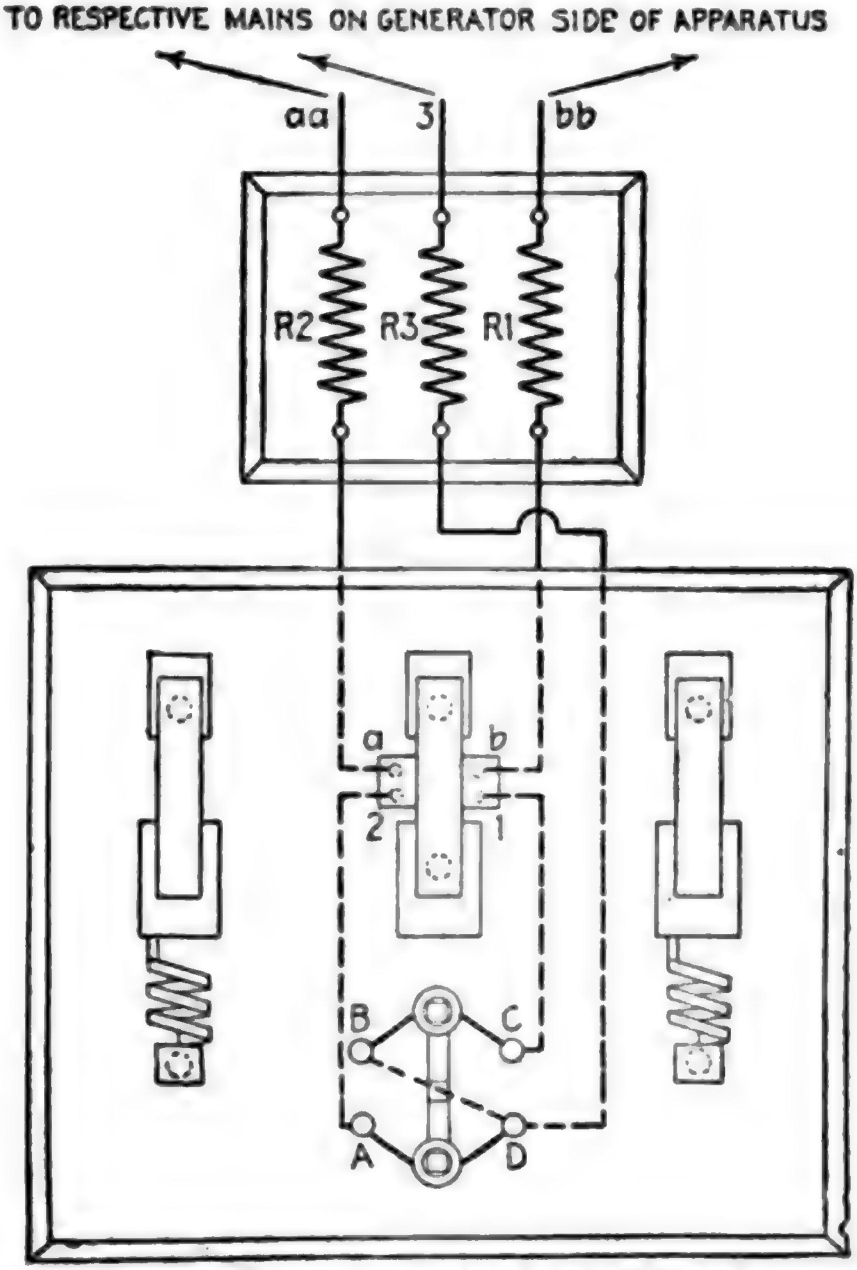

TO RESPECTIVE MAINS ON GENERATOR SIDE OF APPARATUS
PHASE
B
aa
bb
PHASE
A
3
4
R2
R1
a
b
2
1
C
B
D
A
SCHEME OF 2 PHASE 4 WIRE NO VOLTAGE CONNECTIONS


TO RESPECTIVE MAINS ON GENERATOR SIDE OF APPARATUS
PHASE
B
aa
bb
PHASE
A
3
4
R2
R1
a
b
2
1
B
C
A
D

Figs. 2,332 and 2,333.—Diagram showing two phase four wire no voltage connections for I-T-E circuit breaker. The two no voltage coils for two phase four wire circuits are connected respectively to binding posts B, C and A, D on the face of the base. B and D are connected to lower spring contacts 2 and 1 respectively, of the small disconnecting switch. (In instruments supplied on individual bases, these connections are made in the factory, let into channels in back of base and covered with wax.) Each of the upper contacts *a* and *b* of the disconnecting switch is connected respectively through resistance R2 and R1 to one main in each phase at *aa* and *bb*. C and A are respectively connected to the other main in each phase at 3 and 4. Thus each of the no voltage coils operates across one phase independent of the other. The terminals 3, *aa*, *bb* and 4, must, in all cases, be so connected that they will be subject to the full voltage of the circuit, irrespective of the position of the starting switch.

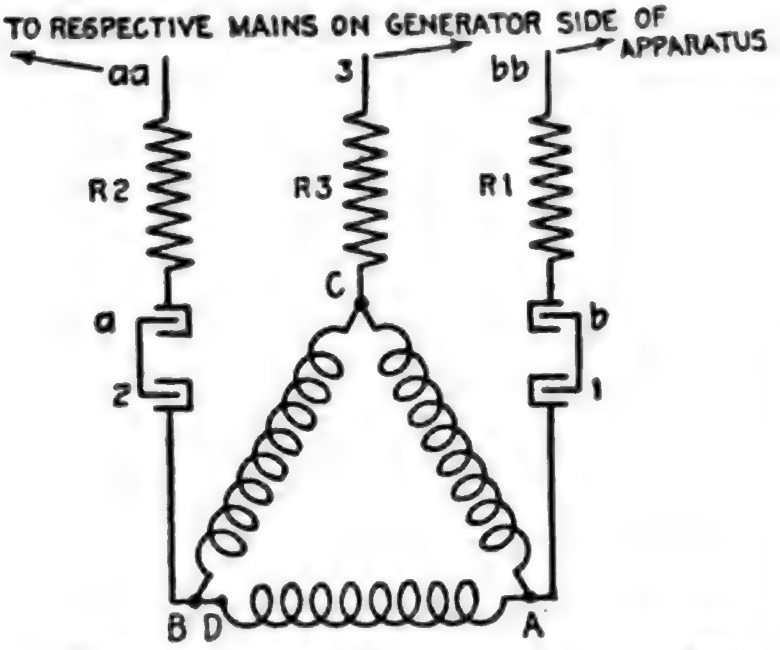

TO RESPECTIVE MAINS ON GENERATOR SIDE OF APPARATUS
aa
3
bb
R2
R3
R1
a
b
2
1
A
D
B
C

SCHEME OF 2 PHASE 3 WIRE NO VOLTAGE CONNECTIONS

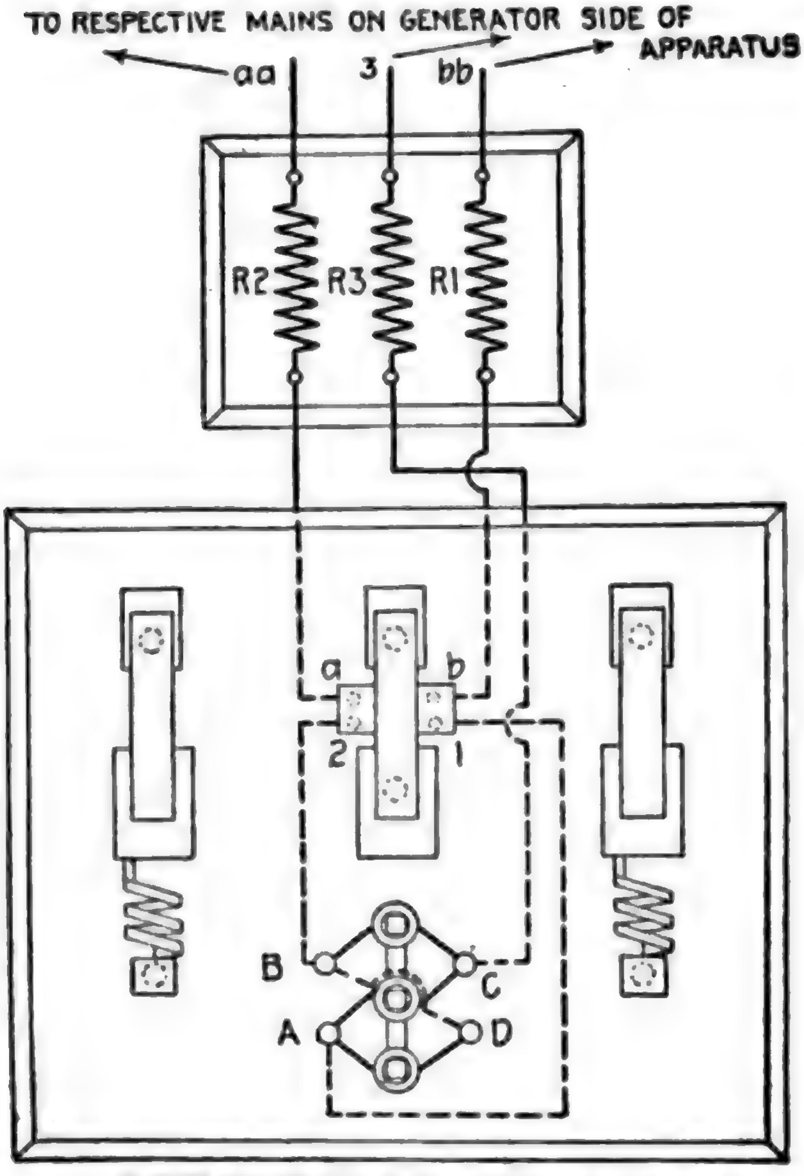

TO RESPECTIVE MAINS ON GENERATOR SIDE OF APPARATUS
aa
3
bb
R2
R3
R1
a
b
2
1
B
C
A
D

2 PHASE 3 WIRE NO VOLTAGE CONNECTIONS

FIGS. 2,334 and 2,335.—Diagram showing two phase three wire no voltage connections for I-T-E circuit breaker. The two no voltage coils for two phase, three wire circuits are connected respectively to binding posts B, C and A D on the face of the base, and from A and C connections are made to lower contacts 2 and 1 respectively of the disconnecting switch. Binding posts B and D are connected together on the back of the board. (In instruments supplied on individual bases, these connections are made in the factory, let into channels in back of base and covered with wax.) Each of the upper contacts *a* and *b* is connected respectively through resistance R2 and R1 to one of the mains at *aa* and *bb* as shown. D is connected through resistance R3 to the common wire of both phases at 3 B and D being connected as aforesaid, thus forming a common connection for both no voltage coils. Terminals *aa* and *bb* of the resistances must be connected to the outside main across the two phases, terminal 3 to the main common to both phases, the connections being so made that these terminals will be subject to the full voltage of the circuit irrespective of the position of the starting switch.


TO RESPECTIVE MAINS ON GENERATOR SIDE OF APPARATUS
aa
3
bb
R2
R3
R1
C
a
b
2
1
B
D
A

SCHEME OF 3 PHASE NO VOLTAGE CONNECTIONS


TO RESPECTIVE MAINS ON GENERATOR SIDE OF APPARATUS
aa
3
bb
R2
R3
R1
a
b
2
1
B
C
A
D

THREE PHASE NO VOLTAGE CONNECTIONS

FIG. 2,336 and 2,337.—Diagram showing three phase no voltage connections for I-T-E circuit breaker. The no voltage coils for three phase circuits are connected in Δ by means of binding posts A, B, C and D on the face of the base, and from the A and B of the no voltage coils, connections are made respectively to spring contacts 1 and 2 of the small disconnecting switch. Each of the contacts *a* and *b* of the disconnecting switch is connected respectively through resistance R2 and R1 to one of the mains at *aa* and *bb*. The terminal C is connected through resistance R3 on the back of the board to the middle main as shown at point 3. The terminal D is linked on the back of the board to terminal B to complete the Δ connection. The terminals *aa*, *bb* and 3 of the circuit breaker must, in all cases, be so connected that they will be *subject to full voltage of the circuit* irrespective of the position of the starting switch. Each no voltage coil is supplied with two terminal wires, one covered with green and one with black insulation. In replacing these coils particular care should be taken to see that the terminal wires connected to any one binding post are of unlike color.

In plants in which two or more banks of transformers are operated in parallel between high and low voltage busses, it is desirable to have for each transformer bank, an automatic circuit breaker equipment which will act selectively and disconnect only the bank in which trouble may occur. With a circuit breaker on each side of transformer bank, selective action may be secured in two ways as follows:

1. By means of an instantaneous differential relay connected in the secondaries of current transformers installed on both the high and low voltage sides of each transformer bank.

The relay operates on a low current, reversal on either side of the bank.

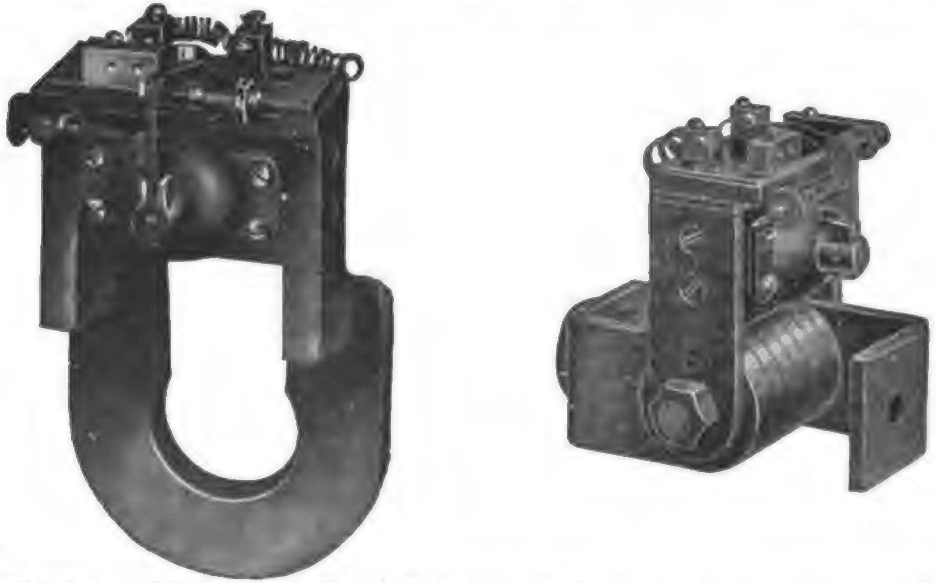
2. By means of one inverse time limit, secondary or series relay installed on that side of the transformer bank which is opposite the source of power, the relay being arranged to trip both the high and low voltage circuit breakers.

The first method has the disadvantage of high first cost due to the high voltage current transformers required, but is more positive than the second method and is independent of the number of transformer banks in parallel.

The second method is the less expensive of the two and protects against overloads as well as short circuits in the transformers, but it is less positive and introduces delay in the disconnection of the transformer when trouble occurs. Furthermore, it is not selective when less than three banks are operating in parallel.

The automatic circuit breakers in the outgoing line may be operated from inverse time limit relays connected in the secondaries of current transformers; or in case transformers are not necessary for use with instruments, series high voltage inverse time limit relays connected directly in the line may be used.

Whether to select current transformers with relays insulated or low voltage, or to choose series relays, is a question of first cost and adaptability to service conditions. Below 33,000 volts, the commercial advantages in favor of the series relay are slight and since it is somewhat difficult to design this device for th large current capacities met with at the lower voltage, it i generally the practice to use the relay with current transforme because of its operating advantage. This practice, however, i not entirely followed, since some service conditions (describe later) make the use of series relays very desirable and practica



FIGS. 2,338 and 2,339.—General Electric instantaneous direct current reverse current or "discriminating" relays. Fig. 2,238, for 500 amperes; fig. 2,339 for 2,000 amperes. Thes relays are designed for mounting directly on circuit breaker studs. **These relays consis** *of a horseshoe magnet with a shunt wound armature pivoted between its poles.* **The magne** is mounted on the current carrying stud of the circuit breaker between the back the panel and the first contact or supporting nut, and is placed in a vertical position. **Th contacts** are insulated from the magnet permitting the use of an auxiliary circuit for th tripping device, independent of the circuit controlled by the circuit breaker. The magne is excited by the current flowing through the stud, and the armature is connected across th line in series with suitable resistance. Rotation of the armature in the normal direction prevented by a stop. **Reversal of the current** flowing through the stud *changes the dire tion in which the armature tends to rotate,* causing it to move away from the stop and clos the circuit through an auxiliary trip coil and trip the circuit breaker. **These relays ar used** to protect dynamos, storage batteries, or main station busses from damage on re versal of current due to short circuit, or from the grounding of machines or connectio Relay contacts must not be used to open the shunt trip coil circuits. An auxiliary swit should be provided for this purpose in all cases where the opening of the circuit breake does not disconnect the trip coil from the source of supply.

Inverse time limit relays are satisfactory for one, or mor than two outgoing lines in parallel as they act selectively to disconnect the defective line only, but installations with only tw outgoing lines in parallel have the same load conditions in both lines and selective tripping of the circuit breakers in the defective line is obtained by means of a selective relay acting instantaneously under short circuit conditions only.

The relay design and action is similar to the reverse current relay previously mentioned, and is connected to the secondaries of current transformers in each high voltage line and pressure transformers in the low voltage bus.

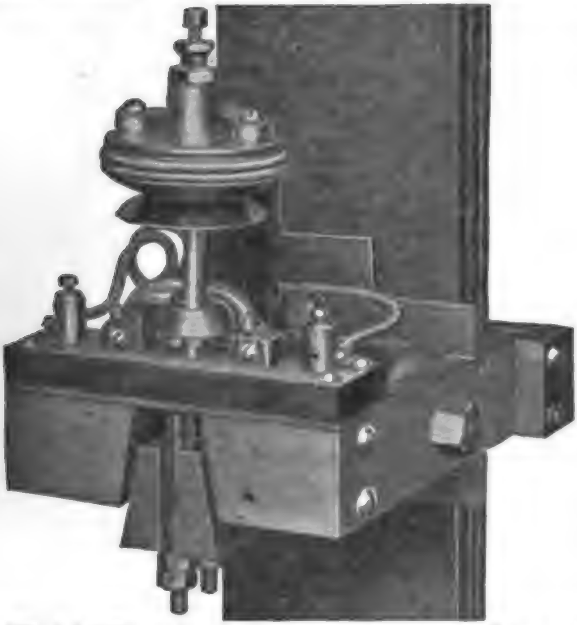


FIG. 2,340.—General Electric **direct current, reverse current relay,** *used to protect dynamos, storage batteries, or main station busses from damage on reversal of current due to short circuits or from the grounding of machine or connections.* It is mounted on vertical bus bars as in the case of cables, on the side wall, or other flat surface, and the cables threaded through the frame. **When used to trip a circuit breaker,** the breaker is provided with a shunt trip connected across the circuit, the tripping circuit being closed through the relay contacts on the occurrence of sufficient reverse current to lift the relay armature. The relay is either instantaneous or time limit as desired. **In the time limit relay,** the time interval is obtained by the leather bellows shown in the illustration. The time setting can be varied within certain limits by means of a valve on the bellows outlet. **The operation of the relay** *depends on the relative value and direction of magnetic flux set up by a pressure coil,* shown in the illustration, *and the current in the vertical bars.* Under normal conditions these fluxes are in the same direction and circulate around a closed magnetic circuit. **When the current in the bars reverse,** *the two fluxes oppose each other and force flux through the normally open leg of the magnetic circuit.* When the reversal of current is of predetermined value, the relay armature is lifted and the purpose of the relay accomplished.

In the sub-station, the conditions are the reverse of those in the main station, the incoming lines becoming the source of power.

If there be only one incoming line and no high voltage bus, the line

circuit breaker is generally non-automatic. With one incoming line and high voltage bus, the circuits from the service side of the bus are equipped with automatic circuit breakers and relays. These relays and those used for other arrangements of two or more incoming lines in parallel, as well as high and low voltage circuit breakers, are of the same design and are applied in the same manner as for the generating station.

Regarding the relay equipments for auxiliary machines, the same practice is recommended with the generator end of alternating current motor generator sets as with the main generators, the outgoing feeder circuit breakers being tripped from inverse time limit or instantaneous relays.

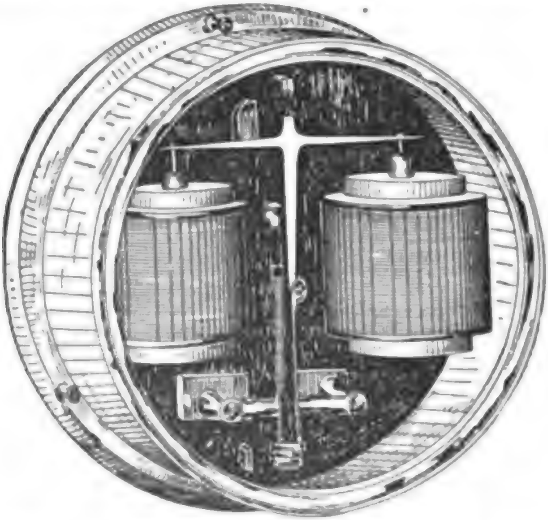


FIG. 2,341.—General Electric **direct current differential relay** for balancer set; instantaneous, 500 (or less) volt type for mounting on panel. In many power plants direct current, three wire, power service is furnished by "high voltage" two wire dynamos operating in connection with balancer sets consisting of two "low voltage" machines on a common shaft. With this combination of machine, a short circuit or heavy overload on one side of the system will shift the neutral considerably, and the lamps on the opposite side may "burn out." To protect the lamps, a differential relay operating on 15 volts unbalancing, is commonly used; it is connected to trip either the dynamo's circuit breakers (or a circuit breaker connected in the bus between the balancer set and the other dynamos).

With several synchronous machines in parallel, the relays are arranged to operate with the least time delay with which it is possible to get selective action, in order to prevent the machines being thrown out of step in event of trouble conditions causing a decrease of voltage.

The various types of *induction motor* and various conditions under which they are employed, have brought about the development of several types of relay to protect the motors and the apparatus with which they are used.

It is desirable to disconnect a *large motor* in case of voltage failure, and with conditions requiring either a motor operated, or a solenoid operated circuit breaker, a *low voltage relay* is used to close the tripping circuit whenever the voltage decreases to, approximately, 50 per cent. below normal.

Up to 550 volts, these relays may be connected across the line, but for higher voltages they are connected to secondaries of pressure

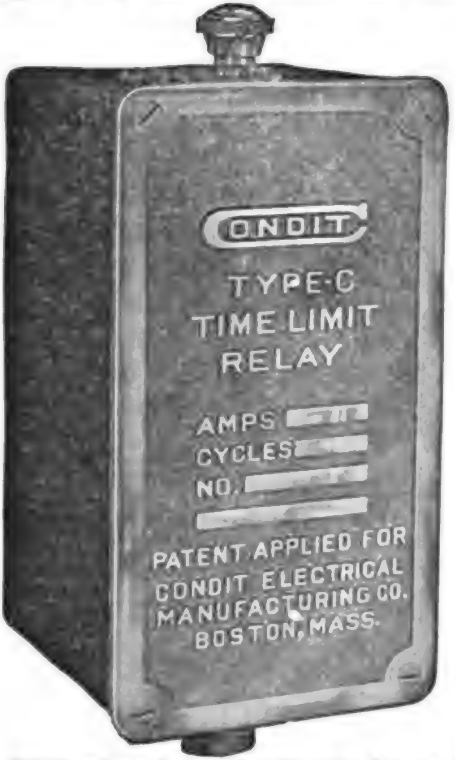


FIG. 2,342.—**Condit time limit relay**, designed primarily for use in connection with feeder circuits, where close selection or discrimination of circuit breakers is not required. **It may be used** satisfactorily on lighting and power circuits and also where there are sudden, momentary fluctuations of current. This relay is used in connection with series transformers. The contact arrangements are provided so that the relays may be used as circuit closing or circuit opening relays. **The delayed action** is produced by an air vacuum dash pot with a graphite piston. The piston of the dash pot is connected to an arm arranged to be moved by the armature. When the current reaches a point where it overcomes the weight of the armature and lifts the same, the magnetic force tending to lift the armature is opposed by the pull of the vacuum created in the interior of the shell into which fits the graphite piston. As the magnetic pull continues the vacuum is overcome due to the leakage of air past the piston, and the armature gradually moves until it reaches a point where it causes the circuit breaker to trip, either by closing the contacts in the circuit closing type, or by opening the contacts in the circuit opening type. If, at any portion of its travel, the current drop to normal, the armature immediately resets. **The time adjustment** consists of an arrangement whereby the distance through which the armature moves before tripping the breaker, may be changed, thus altering the time of tripping. **The current adjustment** is made *by changing the effective turns of the actuating coil*, the travel of the armature and the force exerted by it being the same for all current adjustment. The winding is designed to carry 5 amperes continuously with a temperature rise not exceeding 68° Fahr. standard calibration is provided so that the relay will start to operate at 5, 6, 8 and 12 amperes.

transformers. *Smaller motors* with which hand operated circuit breakers are used, are generally provided with low voltage release attachments that perform the same function as the relay.

Induction motors are sometimes subjected to *high voltage conditions* and to protect them from injury, high or excess voltage relays are employed to trip the automatic circuit breaker.

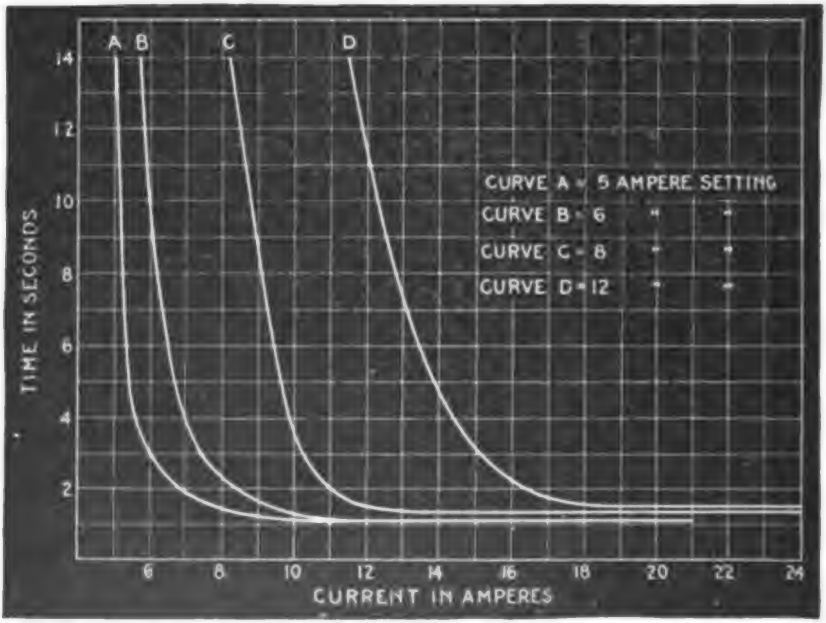


Fig. 2,343.—Characteristic curves of Condit time limit relay as illustrated in fig. 2,342. Settings: curve A, 5 amperes; curve B, 6 amperes; curve C, 8 amperes; curve D, 12 amperes.

These relays are of similar design and wired in the same manner as the low voltage relays.

Reverse phase relays have been developed for operating conditions under which a *reversal of phase* would cause trouble, as for example, in the case of *elevator motors*.

These are so designed that any phase reversal that would reverse an induction motor, would operate the relay and disconnect the automatic circuit breaker.

The design is based on the principle of the induction motor, and in the case of low voltage motors of limited capacity, the relay may be connected in series in the motor leads. If the voltage or capacity of the motor make this arrangement inexpedient, the relay may be placed in the secondaries of current or pressure transformers connected in the motor leads.

Underload relays are often used to trip the automatic circuit breaker that is placed in the primaries of *arc lighting circuits* to prevent an abnormal rise of secondary voltage in case of a break in the secondary circuit.

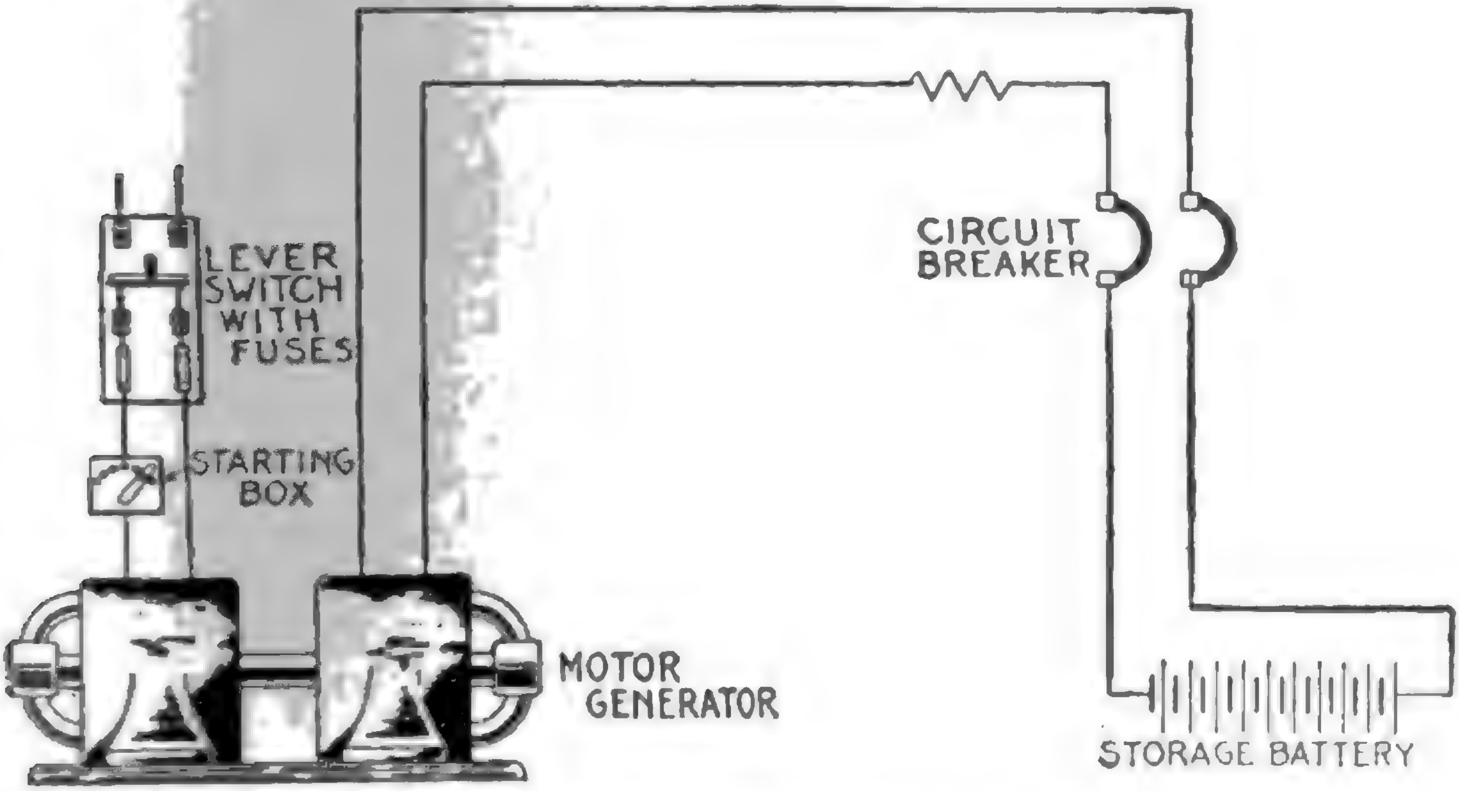


FIG. 2,344.—Diagram showing *storage battery and charging dynamo protected by* **double pole single coil underload circuit breaker.** **In operation,** the *circuit breaker disconnects the battery when fully charged, and protects the dynamo from reverse current.*

The underload relay is similar in design to the low voltage relay excepting that it acts on a decrease of current.

The problem of *protecting induction motors*, from injury, that may result from running on single phase, or from an overload, and at the same time permit the motor to be started with the necessarily high starting current that may be greatly in excess of the overload current, has caused the development of the *series relay.*

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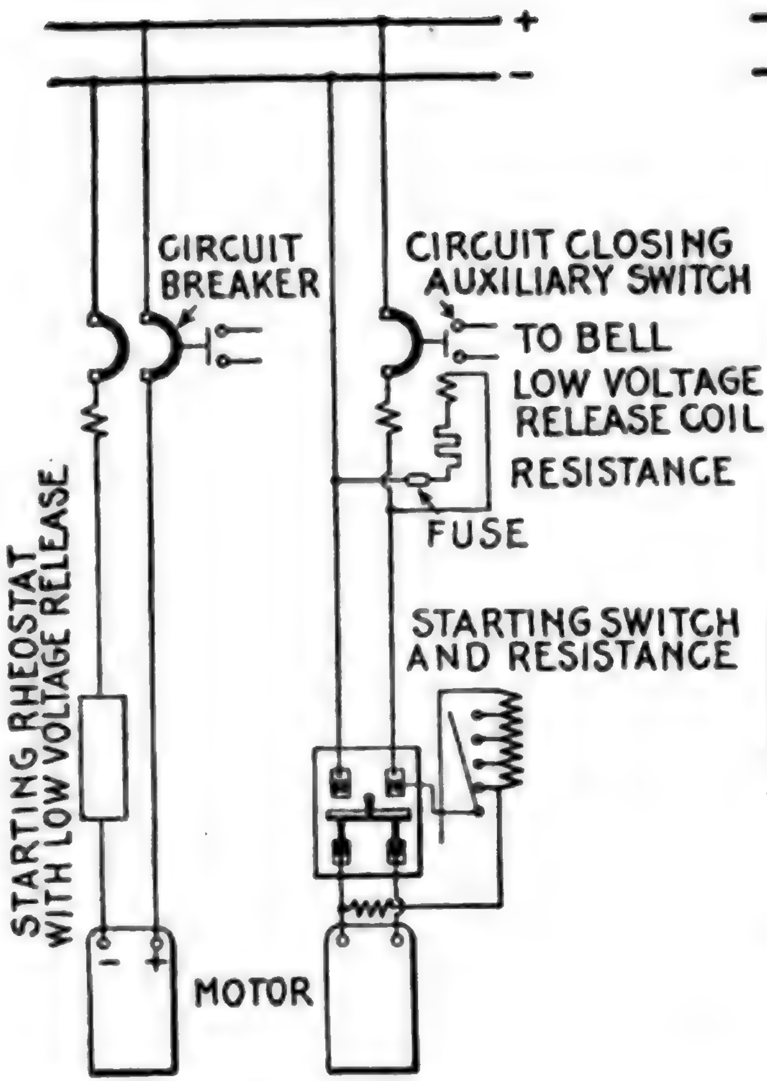
+
−
CIRCUIT BREAKER
CIRCUIT CLOSING AUXILIARY SWITCH
TO BELL
LOW VOLTAGE RELEASE COIL
RESISTANCE
FUSE
STARTING SWITCH AND RESISTANCE
STARTING RHEOSTAT WITH LOW VOLTAGE RELEASE
MOTOR
−
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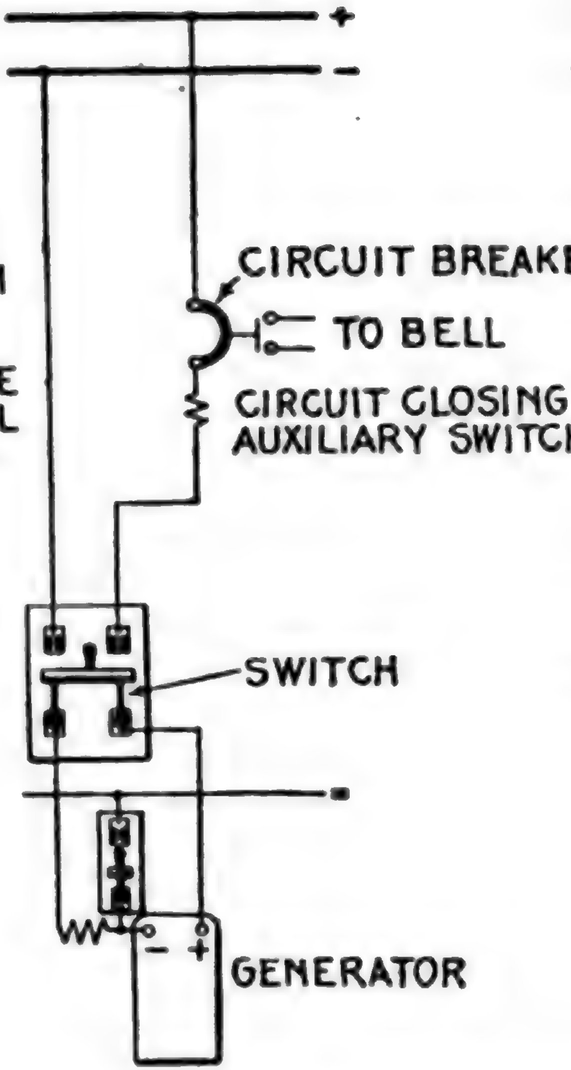
+
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CIRCUIT BREAKER
TO BELL
CIRCUIT CLOSING AUXILIARY SWITCH
SWITCH
GENERATOR
−
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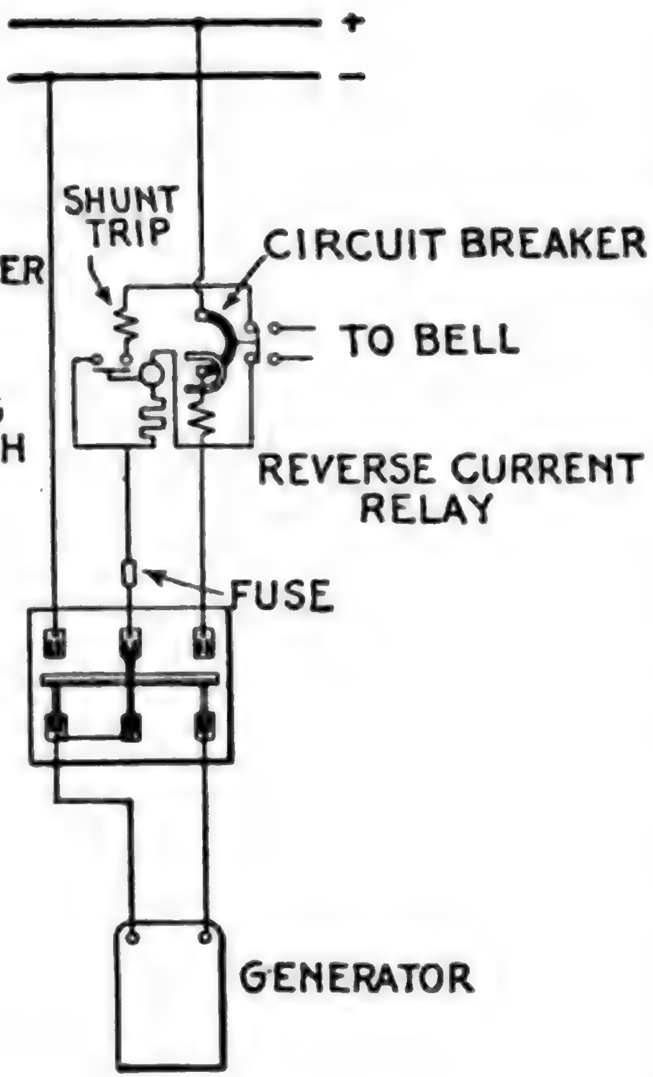

+
−
SHUNT TRIP
CIRCUIT BREAKER
TO BELL
REVERSE CURRENT RELAY
FUSE
GENERATOR

FIG. 2,345.—Diagram showing direct current motors protected by overload circuit breakers with bell alarm switches: *a*, double pole single coil breaker no switch required. Low voltage device is on the starting rheostat; *b*, single pole breaker in series with lever switch. Low voltage attachment on the breaker.

FIG. 2,346.—Diagram showing two wire dynamo, protected by a single pole overload circuit breaker with bell alarm switch. Breakers must be on opposite side from the series field.

FIG. 2,347.—Diagram showing dynamo protected by a single pole overload circuit breaker with reverse current relay and combined circuit opening and bell alarm switch.

This device may be connected in series with the motor leads for voltages up to 2,500; it is designed with an inverse time limit device which may be adjusted to give the desired protection.

The field for relays is more extensive for alternating current than for direct current power circuits, the latter being generally confined to much smaller and simpler systems and areas of distribution, and generally sufficient selective action can be obtained by the use of fuses or circuit breakers arranged with instantaneous trip.

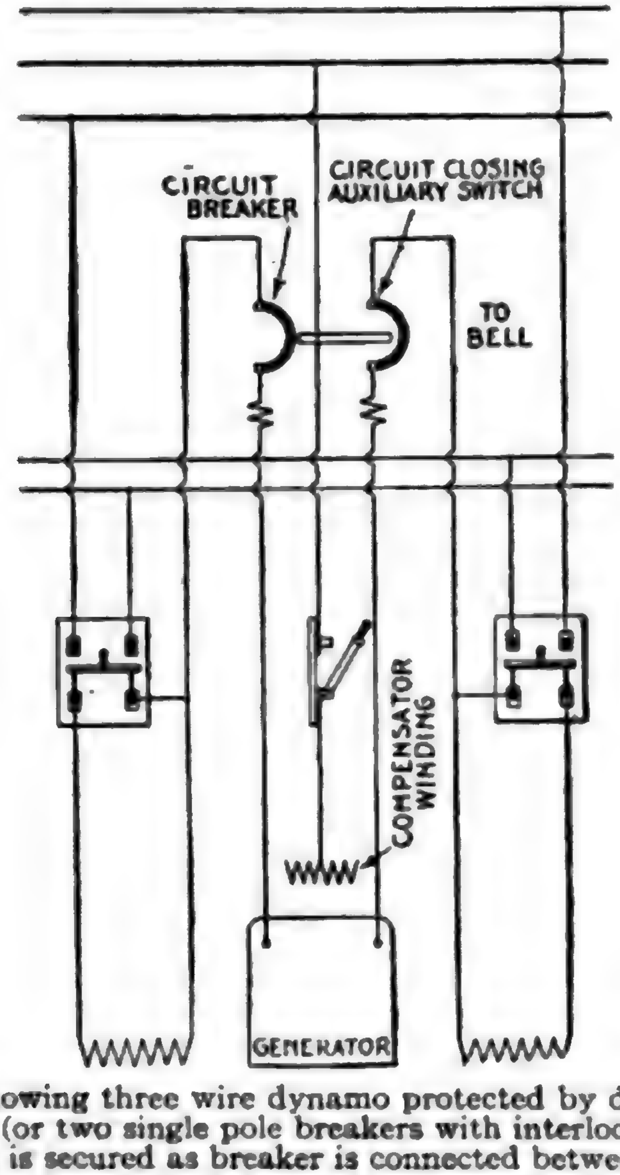


FIG. 2,348.—Diagram showing three wire dynamo protected by double pole double coil overload circuit breaker (or two single pole breakers with interlock) with bell alarm switches. Complete protection is secured as breaker is connected between armature and series field.

Operating conditions sometimes make it advisable for the generator circuit breakers to open only after the auxiliary and feeder circuit breakers have failed to isolate the trouble.

This is accomplished by using direct current *series inverse time limit relays* to trip the generator circuit breakers.

Instantaneous reverse current relays are used to trip the machine circuit breaker of battery charging sets, rotaries and motor generator sets to prevent their running as a motor on the charging or direct current end. These relays can act only in case of current reversal.

To prevent serious unbalancing of voltages in Edison three-wire systems causing trouble, *differential balance relays* are used to trip the circuit breakers on a small percentage of unbalancing.

CHAPTER LIX

LIGHTNING PROTECTION DEVICES

Lightning protection devices, or lightning *arresters*, are evices for providing a path by which lightning disturbances r other static discharges may pass to the earth.

Lightning arresters, designed for the protection of transmission lines, must perform this function with a minimum mpairment of the insulation of the lines.

In general the construction of lightning arresters comprise

1. Air gaps;
2. Resistances;
3. Inductances;
4. Arc suppressing devices.

Ques. What are the causes of static charges?

Ans. They may be caused by sandstorms in dry climates, or may be due to grounds on the high pressure side of a system.

Ques. What causes high frequency oscillations?

Ans. They are usually due to lightning discharges in the vicinity of the line.

Ques. What are the requirements of lightning protection devices?

Ans. They must prevent excessive pressure differences between line and ground, line and line, and between conducto turns in the electrical apparatus.

Air Gap Arresters.—A method of relieving any abnorma pressure condition is to connect a discharge air gap betwee some point on an electric conductor and the ground. Th resistance thus interposed between the ground and the conductor is such that any voltage very much in excess of th maximum normal will cause a discharge to ground, wherea at other times the conductor is ungrounded because of the ai gap. This forms the principle of air gap arresters.

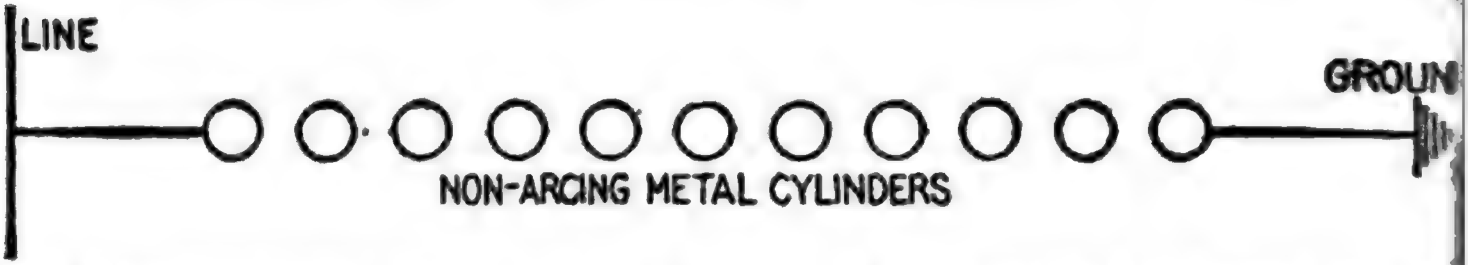
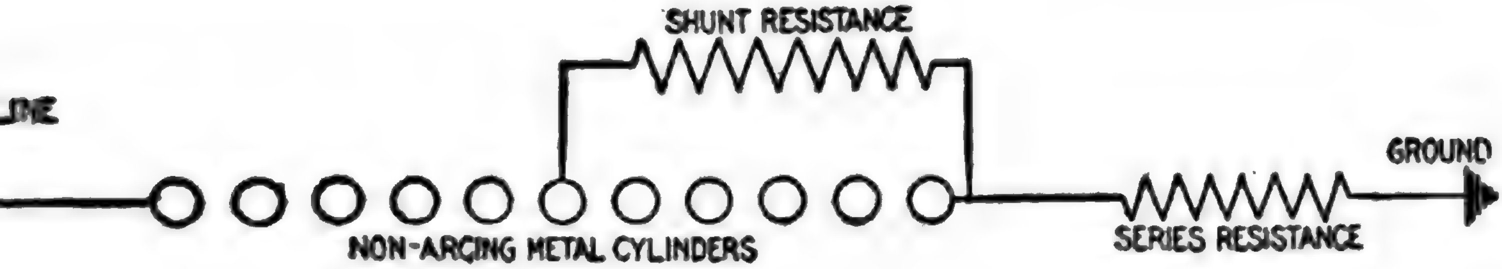


FIG. 2,349.—Non-arcing multigap arrester. Based on the principle of employing for th terminals across which the arc is formed, such metals as are least capable of maintaining a alternating arc between them. This so called non-arcing property of certain metal was discovered by Alexander Wurtz. The action is such that the "line current" which follows the lightning discharge follows as an arc, but is stopped at the end of one alternation because of the property of the non-arcing metals to carry an arc in one direction, but requiring an extremely high voltage to start a reverse arc. The non-arcing metals ordinarily employed are alloys of zinc and copper. Plain multi-gap arresters as here shown operate satisfactorily with the smaller machines and on circuits of limited power, but for large machines of close regulation, and therefore of very large momentary overload capacity, especially when a number of such are operated in parallel, such arresters were found insufficient, the line current following the lightning discharge frequently was so enormous that the circuit did not open at the end of the half wave, that is the arrester held the arc and was destroyed. The introduction of synchronous motors made it necessary that the arc should be extinguished immediately, otherwise the synchronous motors and converters would drop out of step, and the system would in this way be shut down. To insure the breaking of the arc, resistance was introduced in the arrester, the modified device being known as the low equivalent arrester as shown in fig. 2,350.

The single gap while adequate for telegraph line protection, was found insufficient for electric light and power circuits, because since the current in such circuits is considerable and usually at high pressure it would follow the lightning discharge across the gap. Thus the problem arose to devise means for hort circuiting the line current resulting in various modifica-ions of gap arrester.

Multi-gap Arresters.—The essential elements of an arrester f this type are a number of cylinders spaced with a small air ap between them and placed between the line to be protected nd the ground, or between line and line.

In operation, the multigap arrester discharges at a much ower voltage than would a single gap having a length equal o the sum of the small gaps. In explaining the action of multi-aps, there are three things to consider:



IG. 2,350.—Low equivalent arrester. This is a modification of the multi-gap arrester shown in fig. 2,349. About half of the total number of gaps are shunted by a resistance, and another resistance inserted between the cylinders and the earth. With this arrangement the middle point is at ground pressure, and there are between line and ground only one half of the total number of gaps. This is sufficient to prevent a bridging of the gaps under normal conditions.

1. The transmission of the static stress along the line of the cylinders;
2. The sparking at the gaps;
3. The action and duration of the current which follows the spark, and the extinguishment of the arc.

Ques. What is a spark?

Ans. The conduction of electricity by air.

Ques. What is an arc.

Ans. The conduction of electricity by vapor of the electrode.

Distribution of Static Stress.—The cylinders of the multi-g arrester act like plates of condensers in series. This condenser fu tion is the essential feature of its operation.

When a static stress is applied to a series of cylinders between li and ground, the stress is immediately carried from end to end.

If the top cylinder be positive it will attract a negative charge o the face of the adjacent cylinder and repel an equal positive char to the opposite face and so on down the entire row.

The second cylinder has a definite capacity relative to the thi cylinder and also to the ground; consequently the charge induced o the third cylinder will be less than on the second cylinder, due to t fact that only part of the positive charge on the second cylinder induc negative electricity on the third, while the rest of the charge induc negative electricity to the ground. Each successive cylinder, counti from the top of the arrester, will have a slightly smaller charge of ele tricity than the preceding one.

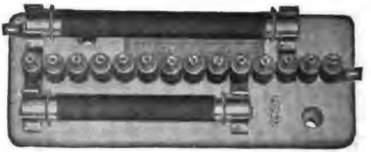


FIG. 2,351.—General Electric 2,200 volt multi-gap arrester for station installation. It co sists of fourteen ⅝" knurled cylinders and two shunt resistance rods mounted on a p celain base. One of these rods has a low resistance, and shunts nine gaps; the oth rod has a high resistance, and shunts eleven gaps. The effect of the shunt resistance i extinguishing the line current arc is the same, therefore, as that of an equal series r sistance but is without the objectionable features of the latter. Series resistance limi the discharge current to such an extent that an arrester with series resistance fails t protect against destructive rises of voltage when the conditions are severest. Grade shunt resistance responds to all frequencies and opens a discharge path for excessi voltage when the frequencies are high as well as when they are low. Its further effe in withholding the line current from the gaps after the relieving discharge has occurred is to aid the non-arcing quality of the metal cylinders in quickly suppressing the arc th follows a discharge. The arc is extinguished at the end of the half cycle of line curre in which the discharge takes place.

Sparking at the Gaps.—The quantity of electricity induced on th second cylinder is greater than on any lower cylinder and its gap has greater pressure strain across it as shown in fig. 2,357. When the vol age across the first gap is sufficient to spark, the second cylinder i charged to line voltage and the second gap receives the static strai and breaks down. The successive action is similar to overturning row of ten-pins by pushing the first pin against the second. This ph nomenon explains why a given length of air gap concentrated in on gap requires more voltage to spark across it than the same total lengt made up of a row of multi-gaps.

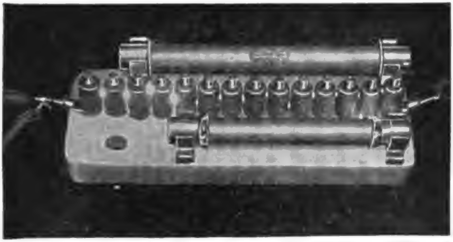
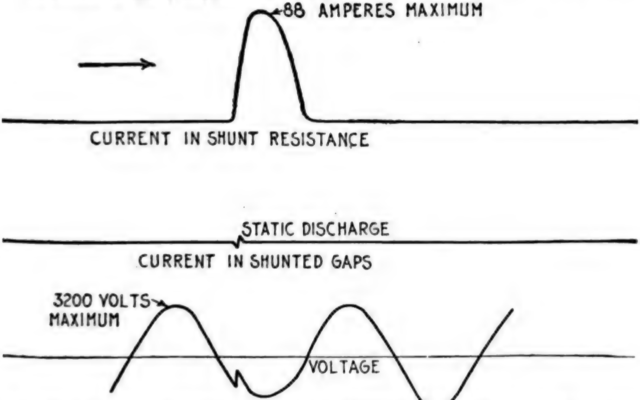


FIG. 2,352.—General Electric 2,200 volt arrester in the act of discharging, and shunting the line current. The figure shows an actual discharge taking place. It will be seen that the heavy line current passes across only four of the gaps, and then goes through the resistance rods; while the static discharge passes straight across the entire series of thirteen gaps. When the gaps of an arrester are shunted by even a low resistance, discharges of very high frequency find it relatively difficult to pass through the resistance rods, owing to the impedance of the rods, but comparatively easy to pass across all the gaps, owing to the capacity effect in breaking down the gaps. The higher the frequency, the more pronounced is this effect, hence the discharges select different paths through gaps and resistances depending upon the frequency. By frequency is meant, not the frequency of the line current but the lightning frequency, which may run into hundreds of thousands, or into millions of cycles. The equivalent needle gap for this arrester is shown by tests to be nearly the same for all frequencies and quantities of discharge; that is, the arrester is equally responsive to all frequencies.

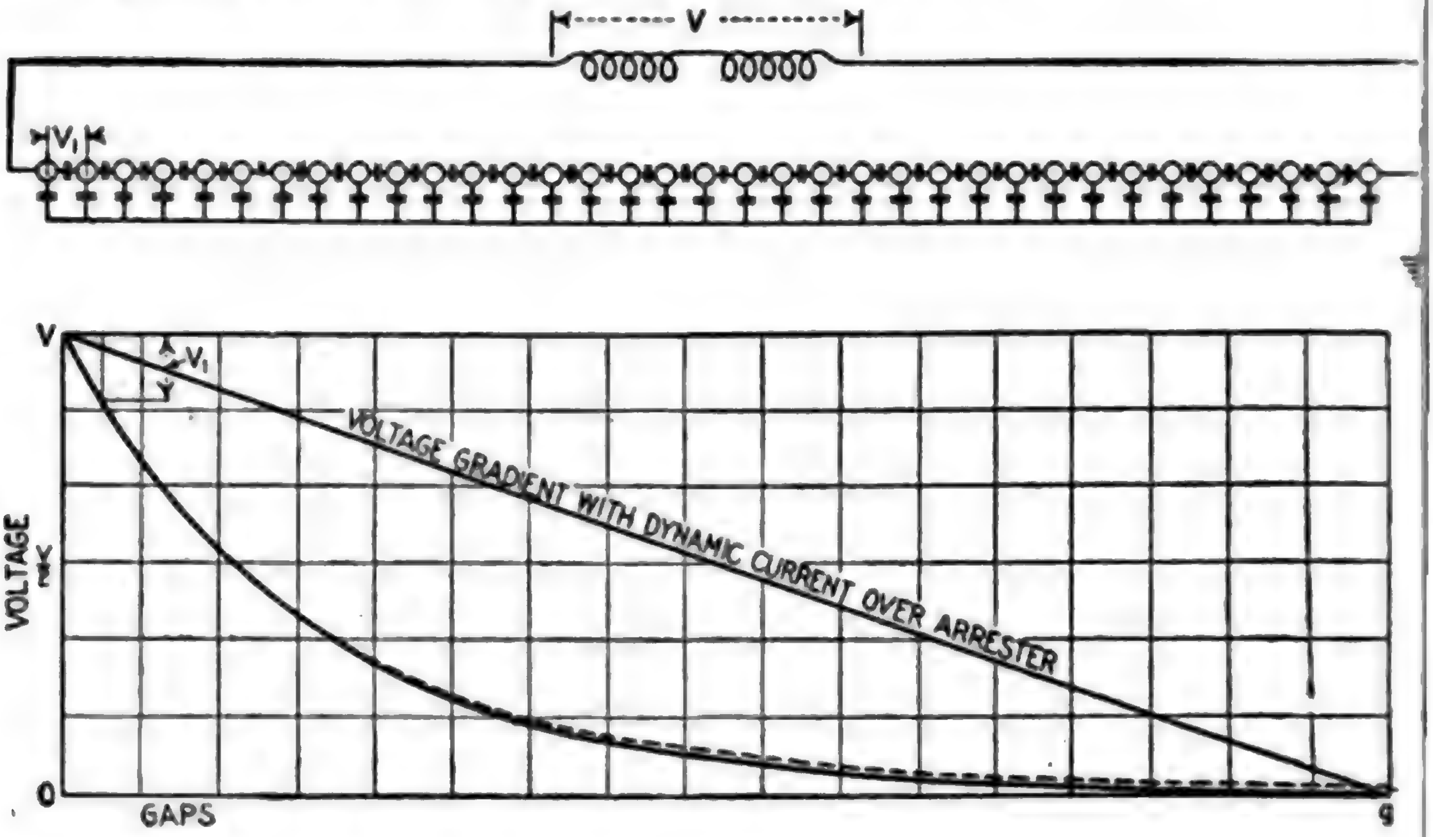


FIGS. 2,353 to 2,355.—Oscillograph record of the phenomena that take place in the different circuits or selective paths of a multi-gap arrester during a discharge such as shown in fig. 2,352.

As the spark crosses each suceessive gap, the voltage gradient alo the remainder readjusts itself.

How the Arc is Extinguished.—When the sparks extend across al the gaps the line current will follow if, at that instant, the line pressu be sufficient. On account of the relatively greater line current, th distribution of pressure along the gaps becomes equal, and has th value necessary to maintain the line current arc on a gap.

The line current continues to flow until the voltage of the generat passes through zero to the next half cycle, when the arc extinguishi quality of the metal cylinders comes into action.



Figs. 2,356 and 2,357.—Diagram showing condenser action of cylinders and pressure gradie for static stress.

The alloy contains a metal of low boiling point which prevents th reversal of the line current. It is a rectifying effect, and before th pressure again reverses, the arc vapor in the gaps has cooled to a non conducting state.

Effect of Frequency.—The higher the frequency of the lightnin oscillation, the more readily will the multi-gap respond to the pressur

Briefly stated, the problem is to properly limit the line current s that the arc may be extinguished; to arrange a shunt circuit so tha the series resistance will be automatically cut out if safety demand i on account of a heavy lightning stroke and, while retaining these prop erties, to make the arrester sensitive to a wide range of frequency.

It should be noted that series resistance limits the rate of discharge of the lightning as well as of the line current. The greater the value of the line current, the greater the number of gaps required to extinguish the arcs.

Graded Shunt Resistances.—Any arc is unstable and can be extinguished by placing a properly proportioned resistance in parallel with it. All the minor discharges then pass over the resistances and the unshunted spark gaps, the resistance assisting in opening the line current after the discharge.

Very heavy discharges pass over all the spark gaps, as a path without resistance, but those spark gaps which are shunted by the resistance, open after the discharge.

The line current, after the first discharge is accordingly deflected over the resistances, and limited thereby, the circuit being finally opened by the unshunted spark gaps. The arrangement of shunted resistances is shown in fig. 2,358.

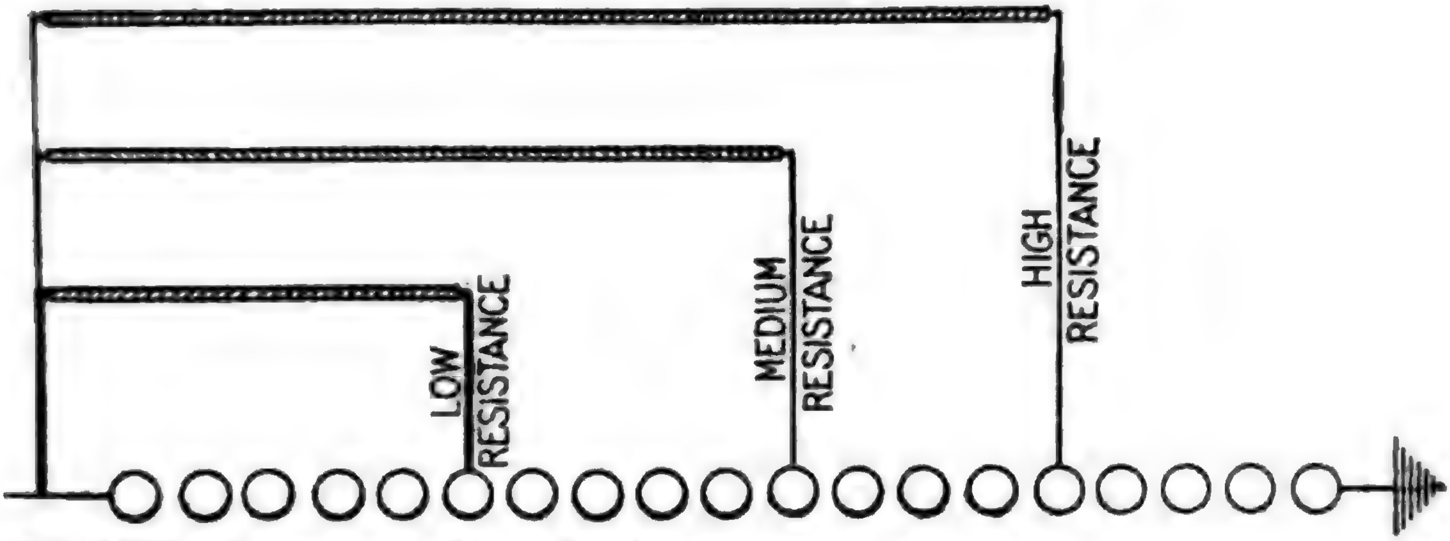


FIG. 2,358.—Arrangement of graded resistances on multigap arrester.

The Cumulative or "Breaking Back" Effect.—The graded shunt resistance gives a valuable effect, where the arrester is considered as four separate arresters. This is the "cumulative" or "breaking back" action.

When a lightning strain between line and ground takes place, the pressure is carried down the high resistance H (figs. 2,365 and 2,366), to the series gaps GS, and the series gaps spark over.

Although it may require several thousand volts to spark across an air gap, it requires relatively only a few volts to maintain the arc which follows the spark. In consequence, when the gaps GS spark over, the lower end of the high resistance is reduced practically to ground pressure.

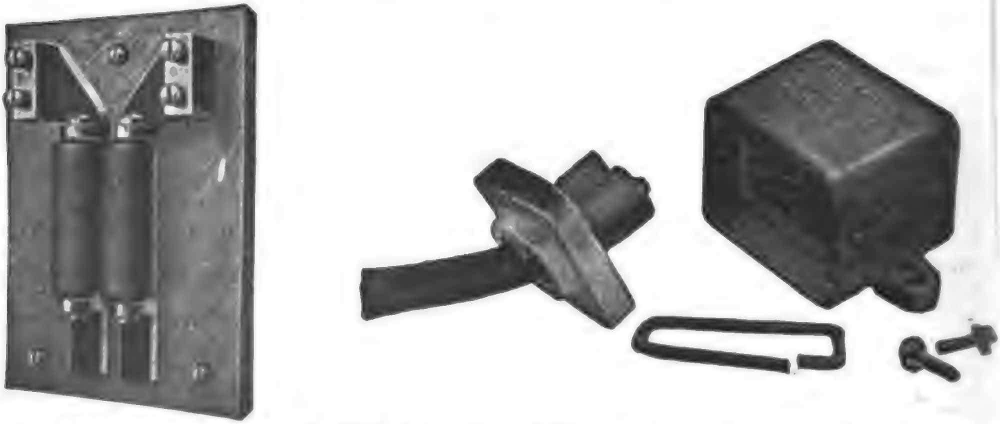
If the high resistance can carry the discharge current without giving an ohmic drop sufficient to break down the shunted gaps GH, nothing further occurs—the arc goes out.

If, on the contrary, the lightning stroke be too heavy for this, the pressure strain is thrown across the shunted gaps, GH, equal in number to the previous set. In other words, the same voltage breaks down both of the groups of gaps, GS and GH, in succession. The lightning discharge current is now limited only by the medium resistance M, and the pressure is concentrated across the gaps, GM.

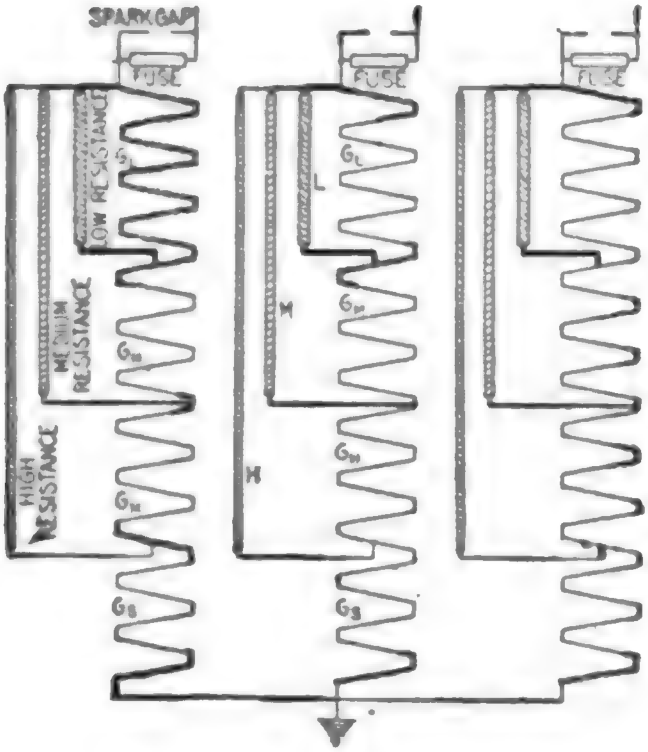
If the medium resistance cannot discharge the lightning, the gap GM spark, and the discharge is limited only by the low resistance.

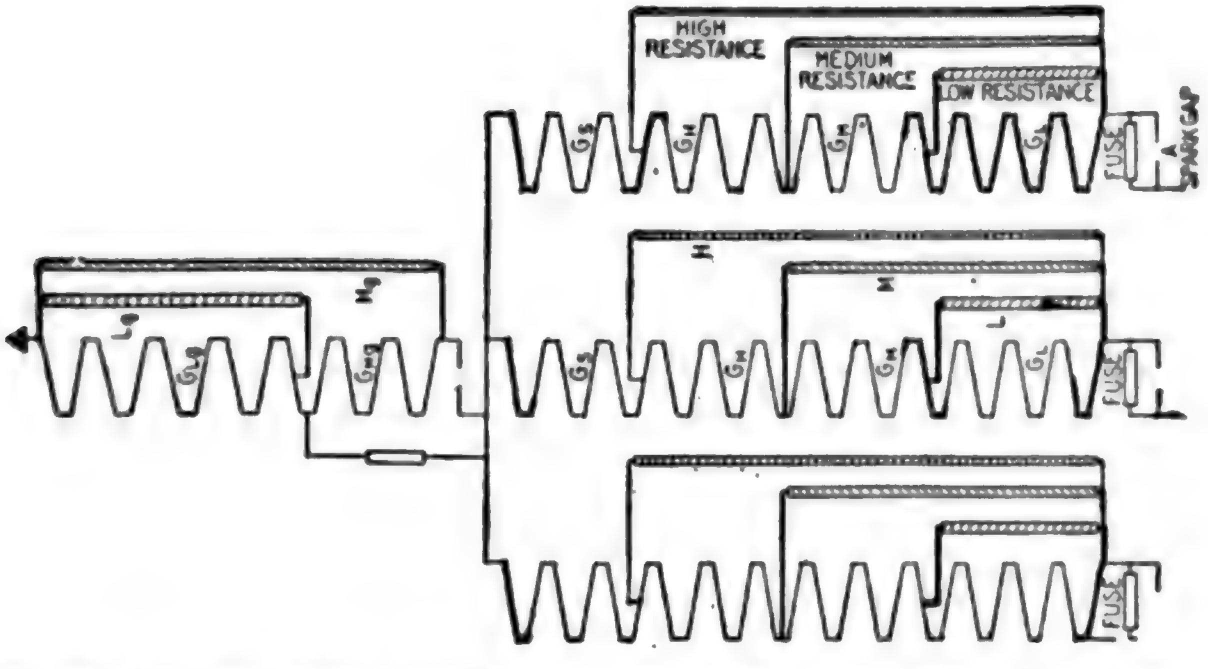
The low resistance should take care of most cases but with extraordinarily heavy strokes and high frequencies, the discharge can **break back** far enough to cut out all resistance.

In the last steps, the resistance is relatively low in proportion to the number of shunt gaps, GL, and is designed to cut out the line current



Figs. 2,359 to 2,364.—Westinghouse safety spark gaps. Fig. 2,359, indoor type; figs. 2,360 to 2,364, outdoor type. It is well known that with transformers, operating on high voltage lines and having large ratios of transformation, there may occur, on the low tension side, momentary voltages to ground greatly in excess of the normal. These momentary increases in voltage between the low tension circuits and ground are commonly called **"static disturbances."** In general they are the result of a change in the static balance of the high tension side and its connecting circuits. Unless certain precautions are taken, such a static disturbance on the low tension side may cause serious stresses in the secondary insulation of a transformer with a high ratio of transformation. This induced static voltage is independent of the ratio of transformation. The static stresses are more serious in a high ratio transformer simply because the insulation of its secondary is less able to withstand them. *A method of relieving this disturbance* is to connect a discharge spark gap between some point of the low tension side of the transformer to be protected (a middle or neutral point, if one be available) and the ground. The spark gap opening is such that any voltage very much in excess of the maximum normal will cause a discharge to ground, and thus the low tension side is practically tied to ground during such disturbance, while at other times it is ungrounded. The Underwriters recommend the grounding of the neutral point of low tension circuits when the conditions are such that the maximum normal voltage between the point connected and ground will not exceed 250 volts. The rule allows one side of a 250 volt circuit or the middle point of a 550 volt circuit to be grounded. **The spark gaps shown above** are designed for use on transformer secondary circuits and for protecting individual series arc lamps. These spark gaps are single pole, and consist of two cylinders of non-arcing metal with an air gap between. One of the cylinders is connected to the ground, the other to the line.


SPARK GAP
FUSE
FUSE
FUSE
LOW RESISTANCE
MEDIUM RESISTANCE
HIGH RESISTANCE
G_L
G_M
G_H
G_S
L
M
H
G_L
G_M
G_H
G_S


HIGH RESISTANCE
MEDIUM RESISTANCE
LOW RESISTANCE
G_S
G_H
G_M
G_L
FUSE
SPARK GAP
H
M
L
G_S
G_H
G_M
G_L
FUSE
FUSE

FIGS. 2,365 and 2,366.—Graded shunt resistance arrester connections. Fig. 2,365, connections for 33,000 volt Y system with grounded neutral; fig. 2,366, connections for 33,000 volt delta or ungrounded Y systems. The type of arrester shown above may be considered as **four arresters in one. First,** for small discharges there are a few gaps in series with a high shunt resistance. This part of the arrester will safely discharge accumulated static and also all disruptive discharges of small ampere capacity. This path is shown through H, (resistance) and GS (gaps). **Second,** there are a number of gaps in series with a medium shunt resistance which will discharge disruptive strokes of medium ampere capacity. This path is shown through M (resistance) and GH plus GS (gaps). **Third,** there are a greater number of gaps in series with a low shunt resistance which will discharge heavy disruptive strokes. This path is shown through L (resistance) and GM plus GH plus GS (gaps). **Fourth,** the total number of gaps has no series resistance, thus enabling the arrester to freely discharge the heaviest induced strokes. This path is shown through zero resistance and GH plus GM plus GH plus GS (gaps). In each of the above circuits the number of gaps and the resistance are so proportioned as to extinguish the line arc at the end of the half cycle in which the lightning discharge takes place.

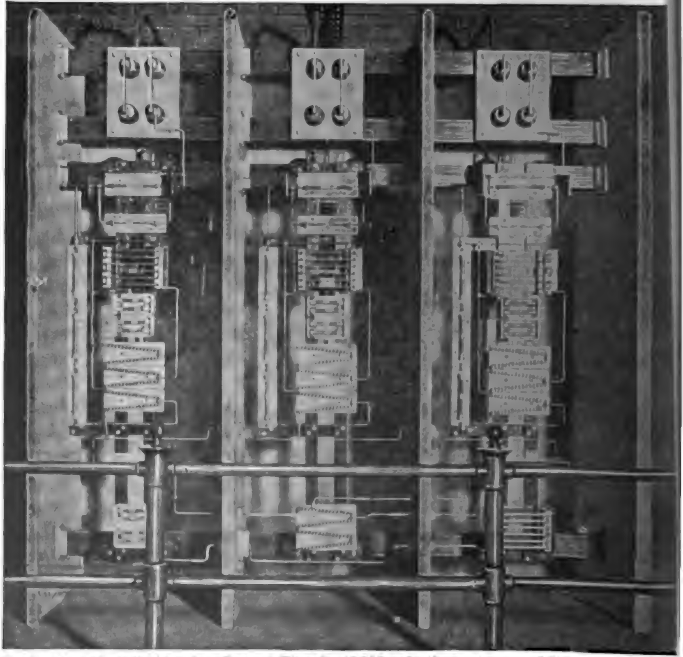


FIG. 2,367.—Installation of a General Electric 12,500 volt, three phase, multi-gap lightning arrester in the Garfield Park sub-station of the West Chicago park common. The "V" unit multi-gap arrester, which is plainly seen in the illustration, is made up of "V" units consisting of gaps between knurled cylinders and connected together at their ends by short metal strips. The base is of porcelain, which thoroughly insulates each cylinder, and insures the proper functioning of the multi-gaps. The cylinders are made of an alloy that contains metal of low boiling point which gives the rectifying effect, and metals of high boiling point which cannot vaporize in the presence of the one of low boiling point The cylinders are heavily knurled. As the arc plays on the point of a knurl it gradually burns back and when the metal of low boiling temperature is used up, the gap is increased at that point. The knurling, thus, insures longer life to the cylinder by forcing successive arcs to shift to a new point. When worn along the entire face, the cylinder should be slightly turned. The low resistance section of the graded shunt is composed of rods of a metallic alloy. These rods have large current carrying capacity, and practically zero temperature coefficient up to red heat. The medium and high resistance rods are of the same standard composition previously used. The contacts are metal caps shrunk on the ends; the resistances are permanent in value and the inductance is reduced to a minimum. The rods are glazed to prevent absorption of moisture and surface arcing.

immediately from the gap, GL. This "breaking back" effect is valuable in discharging lightning of low frequency.

After the spark passes, the arcs are extinguished in the reversed order. The low resistance, L, is proportioned so as to draw the arcs immediately from the gaps, GL. The line current continues in the next group of gaps, GM, until the end of the half cycle of the generator wave.

FIGS. 2,368 to 2,370.—Multi-gap or low equivalent lightning arrester. It consists of: 1, a number of gap units in series; 2, a number of gap units in shunt with a resistance; and 3, a series resistance. All **resistances** are wire wound and the series resistance is non-inductive. The shunt resistance and gap units are mounted on marble. **When a discharge occurs,** the series gaps are broken down, and if the discharge be heavy enough, it will find opposition in the shunt resistance and pass over the shunted gaps, through the series resistance to the ground. **The arc** which tends to follow the discharge is then withdrawn from the shunted gaps by the shunt resistance, and aided by both resistances is suppressed by the series gaps. **The pressure of discharge** is determined by the number of series gaps as sufficient number is used to withstand the normal voltage and yet give a large factor of safety for the severest service.

At this instant the medium resistance, M, aids the rectifying quality of the gaps, GM, by shunting out the low frequency current of the alternator.

On account of this shunting effect the current dies out sooner in the gaps, GM, than it otherwise would.

In the same manner, but to a less degree, the high resistance, H, draws the line current from the gaps, GH.

This current now being limited by the high resistance, the arc is easily extinguished at the end of the first one-half cycle of the alternator wave.

Ques. What is the difference between arrester for grounded Y and non-grounded neutral systems?

Ans. The connections are shown in figs. 2,365 and 2,366. The difference in design lies in the use of a fourth arrester leg between the multiplex connection and ground or ungrounded system.

Ques. Why is the fourth leg introduced?

Ans. The arrester is designed to have two legs between line and line. If one line become accidentally grounded, the full line voltage would be thrown across one leg if the fourth or ground leg were not present.

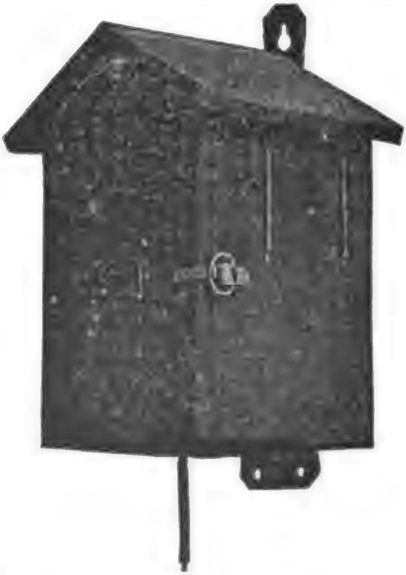


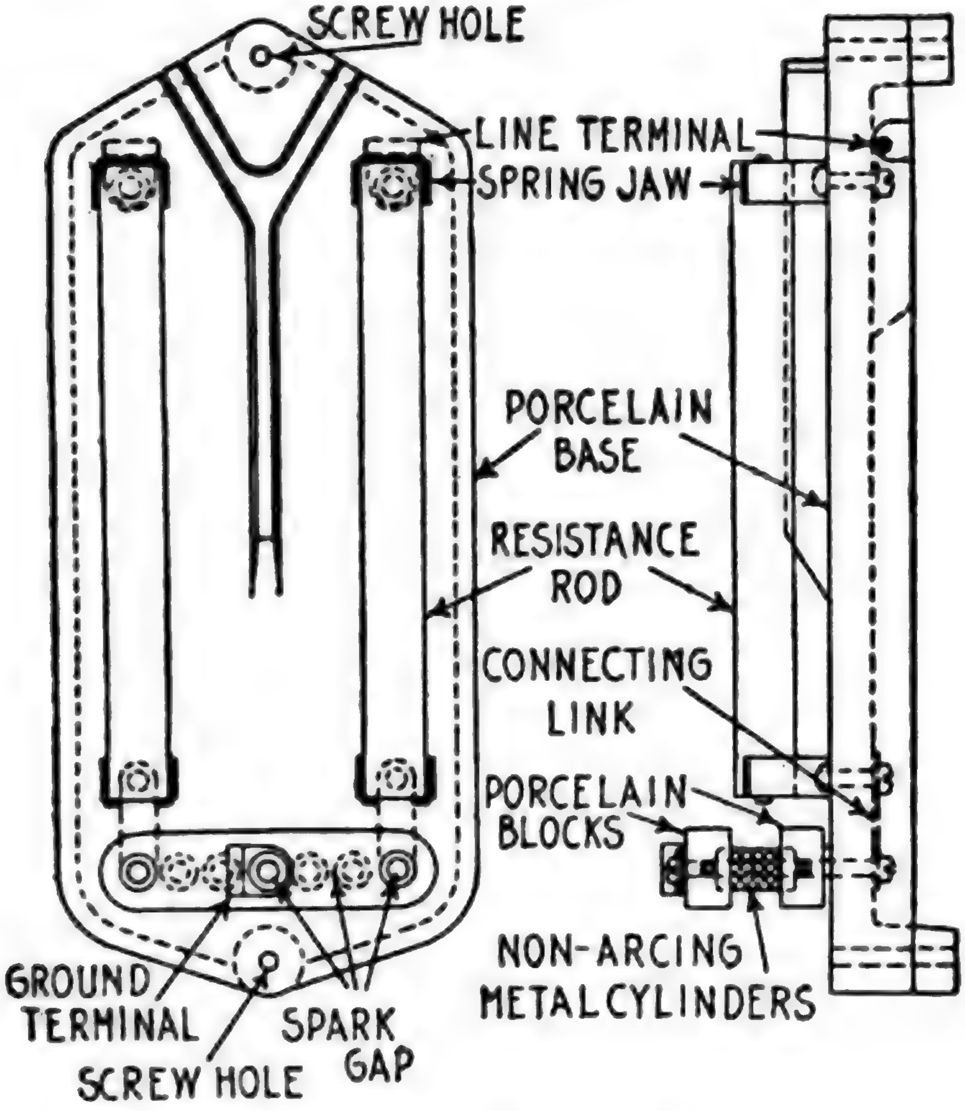
FIG. 2,371.—Westinghouse three pole or four pole arrester in weather proof wooden case which protects the arrester units from rain and snow when they are installed in exposed locations, as on poles or buildings.

On a **Y** system with a grounded neutral, the accidentally grounded phase causes a short circuit of the phase and the arrester is relieved of the strain by the tripping of the circuit breaker. Briefly stated, the fourth or ground leg of the arrester is used when, for any reason, the system could be operated, even for a short time with one phase grounded.

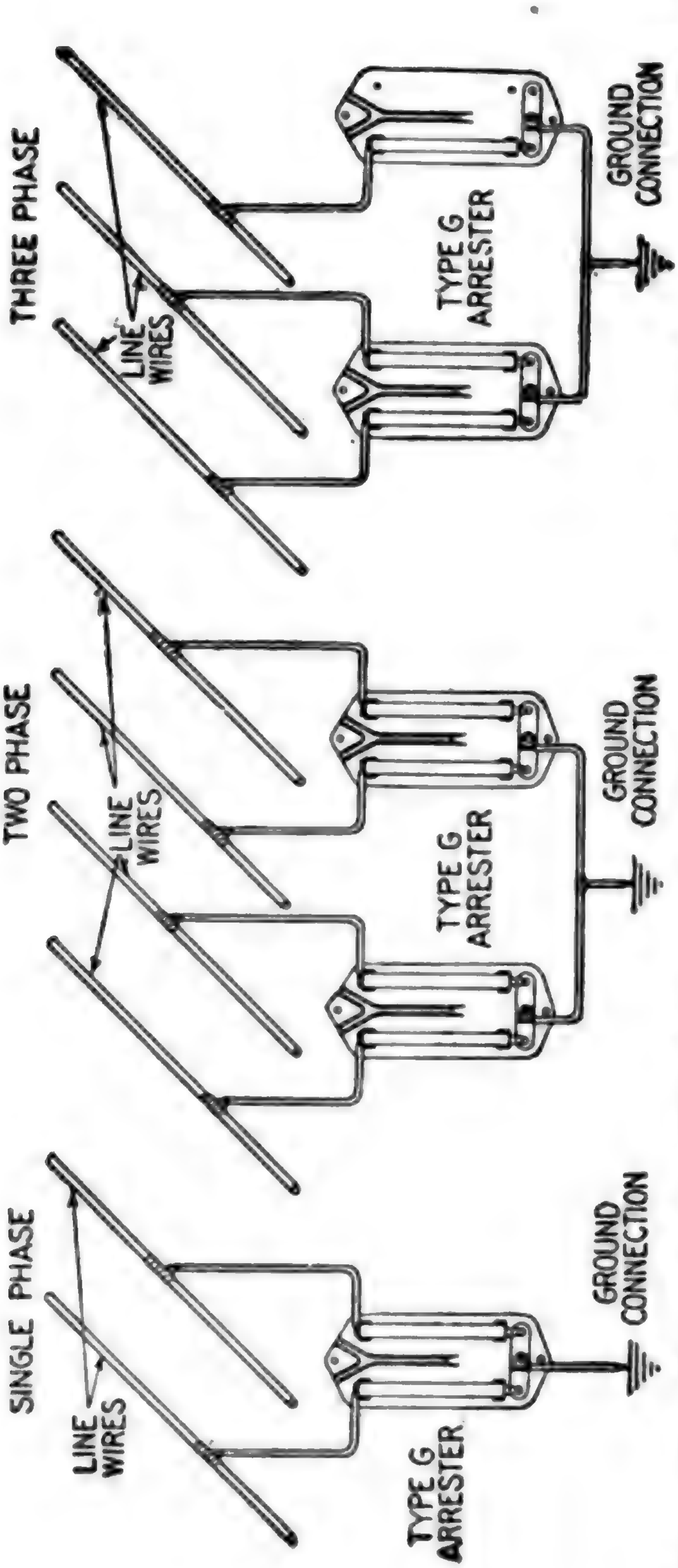
Ques. Describe the multiplex connection.

Ans. It consists of a common connection between the phase legs of the arrester above the earth connection and provides an arrester better adapted to relieve high pressure surges between lines than would otherwise be possible.

Its use also economizes in space and material for delta and partially grounded or non-grounded **Y** systems.


SCREW HOLE
LINE TERMINAL
SPRING JAW
PORCELAIN BASE
RESISTANCE ROD
CONNECTING LINK
PORCELAIN BLOCKS
NON-ARCING METAL CYLINDERS
GROUND TERMINAL
SPARK GAP
SCREW HOLE

FIGS. 2,372 and 2,373.—Westinghouse multi-gap lightning arrester and views showing parts. **In construction**, a series of gaps, between non-arcing metal cylinders arranged in a row, is connected between line and ground in series with a composition stick resistor having a resistance of something between 80 and 120 ohms. **In operation**, if an excessive pressure be developed on a line, electric discharge arcs form between the metal cylinders, and the charge of electricity flows to ground, relieving the excessive stress. The resistance of the stick resistor limits the flow so that an excessive power current cannot pass through the arrester. The tendency for a destructive power arc to follow the discharge arc is thus counteracted. **The composition resistors** and the gap cylinders are mounted in pairs on a porcelain base, and complete units are arranged within weather proof wooden boxes as indicated. **For two pole arresters**, one unit is mounted on the back of the box. **For three pole and four pole arresters, two units are used; one is secured on each side of the box.**


SINGLE PHASE
LINE WIRES
TYPE G ARRESTER
GROUND CONNECTION
TWO PHASE
LINE WIRES
TYPE G ARRESTER
GROUND CONNECTION
THREE PHASE
LINE WIRES
TYPE G ARRESTER
GROUND CONNECTION

FIGS. 2,374 to 2,376.—Connections for Westinghouse multi-gap (type G) arresters. These arresters may be installed outside on poles or buildings, or indoors on station walls. The weather proof wooden case (as shown in fig. 2,371) protects the arrester units from rain and snow when installed in exposed places. Fig. 2,374 shows single phase installation, fig. 2,375, two phase installation, and fig. 2,376, three phase installation. **On a two pole circuit** one line wire is connected to the top of each of the composition resistors of each arrester unit, as shown in fig. 2,374, and the ground wire is connected to the middle point of the gap series. **On four pole circuits**, fig. 2,375, the same scheme of connections is used, but two arrester units are necessary and the connections of both are the same. **On three pole circuits**, two arrester units are used, with the same connections as for four pole circuits, except that there are but three line connections instead of four as in fig. 2,376.

Horn Gap Arresters.—A horn gap arrester consists essentially of two horn shaped terminals forming an air gap of variable length, one horn being connected to the line to be protected and the other to the ground usually through series resistance as shown in fig. 2,378.

Ques. How does the horn gap arrester operate?

Ans. The arc due to the line current which follows a discharge, rises between the diverging horn and becoming more and more attenuated is finally extinguished.

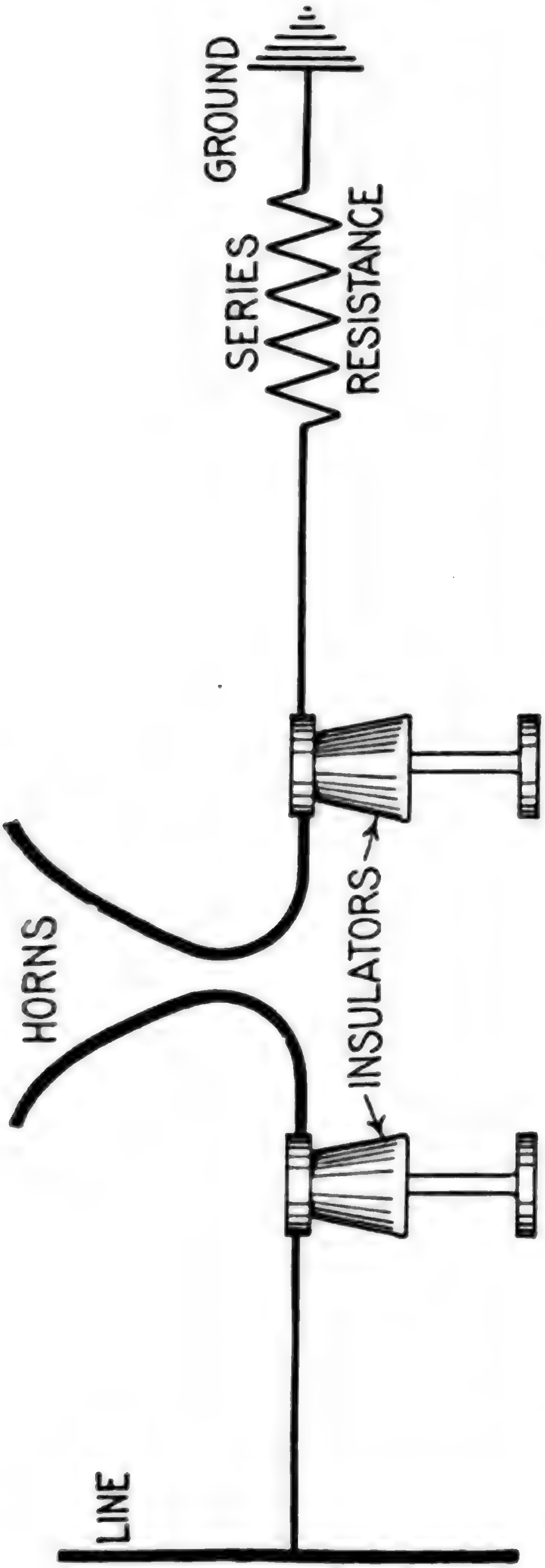


FIG. 2,377.—Horn gap arrester, diagram showing arrester and connections between line and ground. The horn type arrester was invented by Oelschlaeger for the Allgemeine Electricitaets Gesellschaft, and like the Thomson arc circuit arrester, its operation is based on the fact that *a short circuit once started at the base, the heat generated by the arc will cause it to travel upward until it becomes so attenuated that it is ruptured.* On circuits of high voltage this rupture sometimes takes a second or two, but seems to act with little disturbance of the line. Sometimes a *water resistance* is used, a *choke coil being* inserted in the circuit in series. In one installation for a 40,000 volt line, the horns were made of No. 0,000 copper wire with gap knees 2½ to 3 or 3½ inches. The capacity of the water resistance receptacle was 15 gallons. Users differ as to whether the water should contain salt. The choke coil can be made of about 18 turns of iron wire wound on a 6 inch cylinder.

Ques. What is the objection to the horn gap on alternating current circuits?

Ans. The arc lasts too long for synchronous apparatus to remain in step.

Ques. What provision was made to shorten the duration of the arc ?

Ans. A series resistance was inserted in the arrester circuit as shown in fig. 2,377.

Ques. What difficulty was caused by the series resistance?

Ans. With sufficient series resistance to prevent loss of synchronism, the arrester failed to protect the system under severe conditions.

Ques. With these objections what use was found for the horn gap arrester?

Ans. It is used as an emergency arrester on some overhead lines, to operate only when a shut down is unavoidable, also for series lighting circuits.

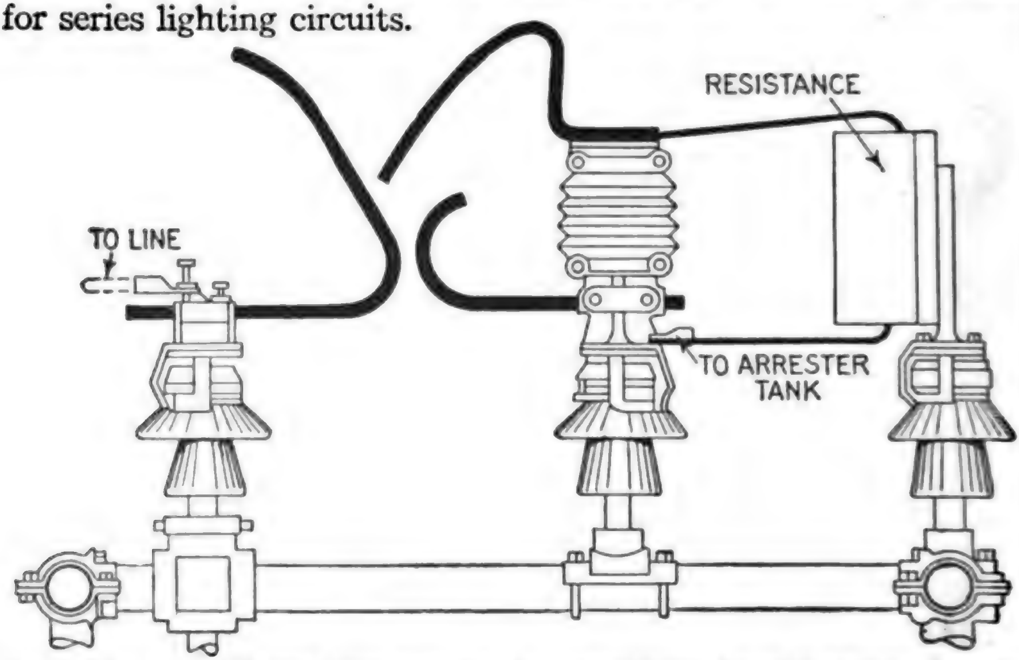
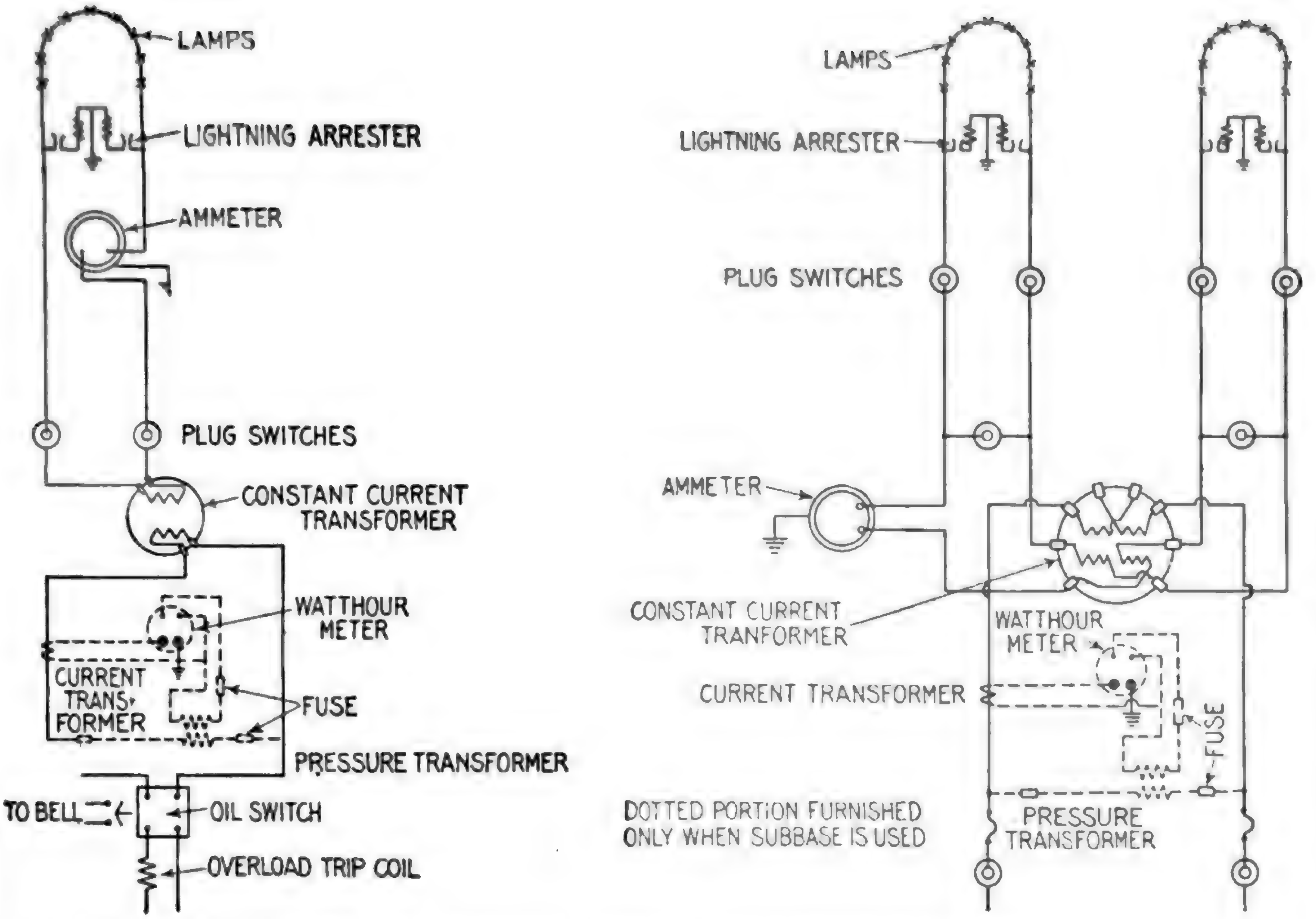


FIG. 2,378.—General Electric horn gap with charging resistance for cable system. Arresters for cable systems differ from arresters for overhead circuits only in the construction of the horn gaps. The necessity for this difference is due to the fact that a cable system has a very much higher electrostatic capacity and much less inductance than an overhead system. In consequence, the currents which flow into the arrester during charging are somewhat higher. It is desirable to avoid these heavier currents, especially during the time of breaking the arc at the horn gap. This is accomplished by using a special horn gap and resistance. This consists of an auxiliary horn mounted above and insulated from the regular horn in such a manner as to intercept the arc if it rise on the regular horns. Enough resistance is connected in series with this auxiliary horn so that the current flow and arc across this gap are always limited to a moderate value. Such a device has several advantages. Since the mechanism is so arranged that the charging is always done through the auxiliary horn the current rush is limited during the charging and thus troubles from carelessness or ignorance are avoided. It also gives a nearer uniform charging current. In the use of this auxiliary horn gap and resistance there are three successive stages, as follows: 1, light discharges will pass across the smaller gaps to the auxiliary horn and through the series resistance to the cells; 2, if the discharge be heavy, the resistance offers sufficient impedance to cause the spark to pass to the main horn. This is accomplished with only a slight increase in pressure because the gap is already ionized. If the cells be in normal condition, the spark at the gap is immediately extinguished without any flow of line current; 3, if the cells be in poor form, the line current may follow the discharge across the main gap and the arc will rise to the safety horn and be extinguished through a resistance. For mixed overhead and cable systems the choice of arrester will be a matter of judgment. If there be a comparatively short length of cable, the usual practice for overhead systems may be adopted. For direct connection to busbars, arresters with charging resistance should be used.


LAMPS
LIGHTNING ARRESTER
AMMETER
PLUG SWITCHES
CONSTANT CURRENT TRANSFORMER
WATTHOUR METER
CURRENT TRANS-FORMER
FUSE
PRESSURE TRANSFORMER
TO BELL
OIL SWITCH
OVERLOAD TRIP COIL
LAMPS
LIGHTNING ARRESTER
PLUG SWITCHES
AMMETER
CONSTANT CURRENT TRANFORMER
WATTHOUR METER
CURRENT TRANSFORMER
FUSE
DOTTED PORTION FURNISHED ONLY WHEN SUBBASE IS USED
PRESSURE TRANSFORMER

FIGS. 2,379 and 2,380.—Diagram showing connections of horn type lightning arresters on series circuits.

The necessity of service requires that series lightning systems be fully equipped against damage by lightning and similar trouble. The most common disturbances occurring on series circuits are the surges set up by the sudden opening of the loaded circuit. These disturbances are especially severe where circuits are accidentally grounded, due to contact of the wires where they pass through other circuits.

Ques. How are the spark gaps adjusted?

Ans. They are set to give a low spark pressure relative to the voltage of the line.

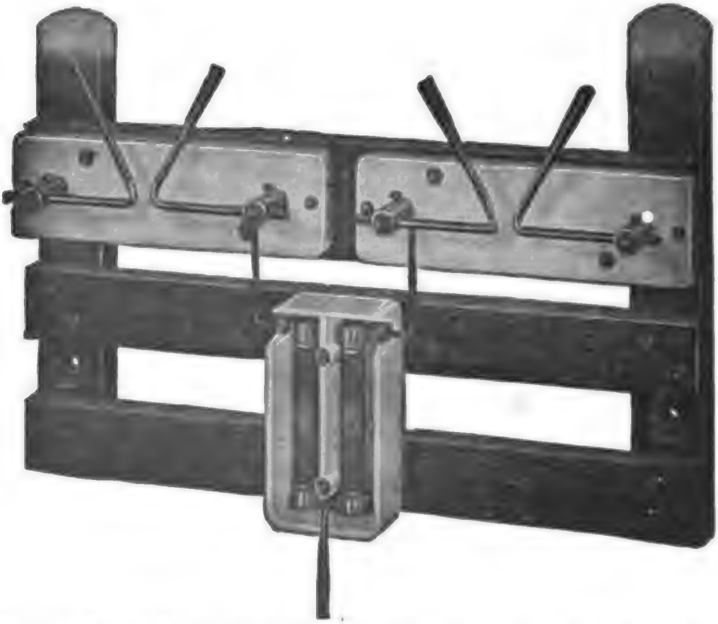


FIG. 2,381.—General Electric horn type arrester, mounted for 15 light series arc circuit. The horn type arrester consists of a horn gap with series resistance between each line and ground. The resistances and horn gaps are mounted on porcelain bases and the latter on insulating wooden supports. The supports have asbestos barriers (except for lowest voltages), and backs to eliminate liability of damage from the arc which forms in the horn gap at the time of the discharge. The spark gaps are adjusted to give a low spark pressure relative to the voltage of the circuit. The number and ohmic value of the resistance rods used in the various arresters depend upon the voltage and current of the circuit.

Ques. Why are horn arresters well suited to protect series lighting circuits against surges?

Ans. Because the surges are damped out before the arc which forms across the horn gaps is interrupted.

These arcs last for several cycles, since the length of the time of action of the arrester depends upon the lengthening of the arc between the horn gaps, limited by the series resistance.

Since practically all disturbances on lighting circuits are of low frequency, the series resistance can be used with good results; it aids the horn in extinguishing the arc, limits the size of the arc and prevents short circuits occurring during the period of discharge.

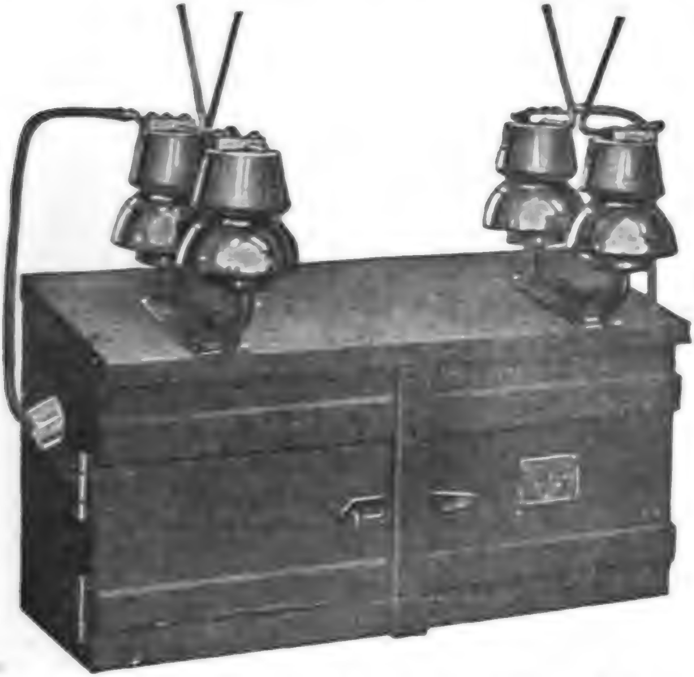
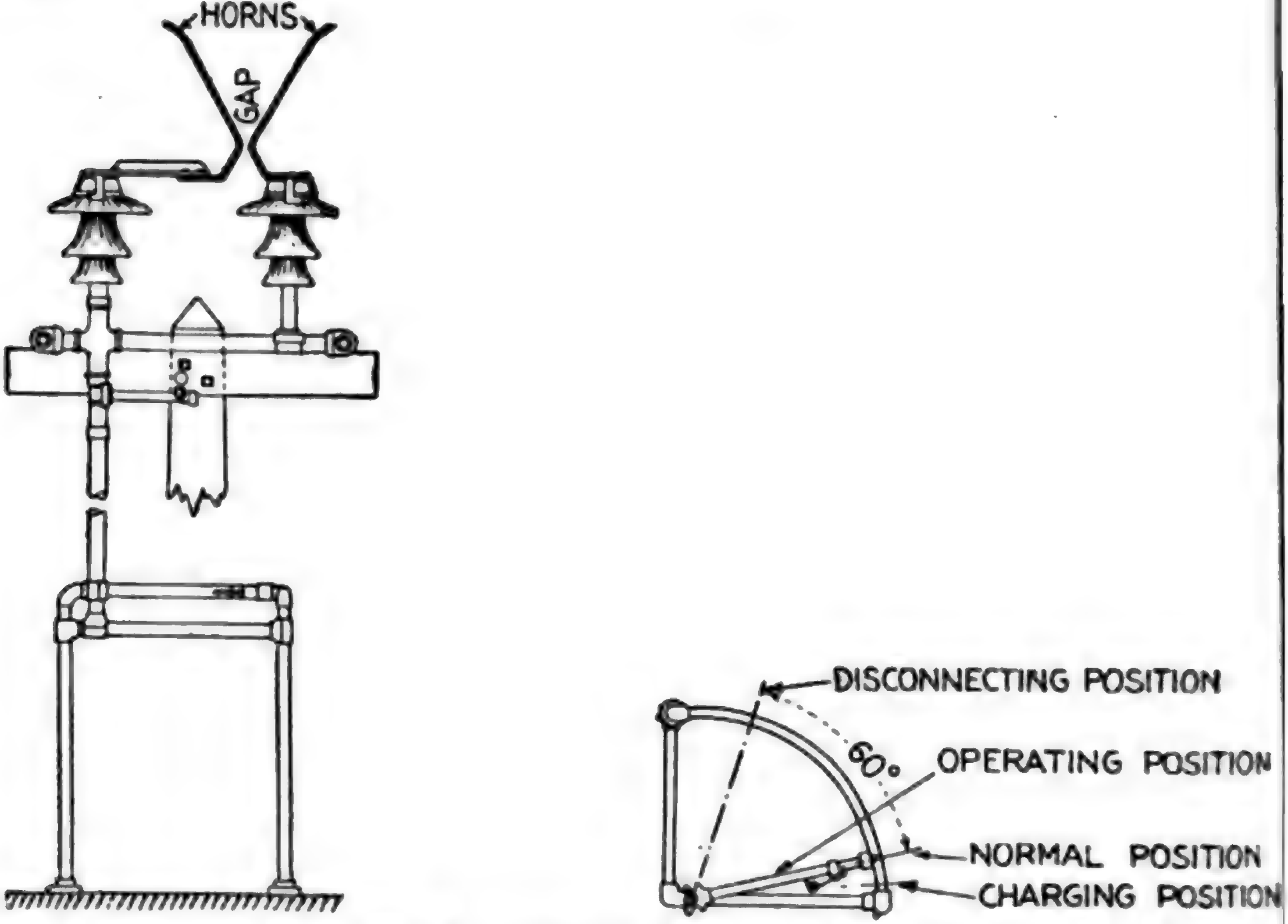


FIG. 2,382.—General Electric horn arrester for pole installation. Quite frequently series circuits are run underground in cables for some distance from the generating station. In order to protect the cables it is advisable to place horn arresters at the points where the cable joins the overhead wires. The resistance units are mounted in the wooden box. This design is used to economize space, since if the horn gaps be placed in the box the latter would have to be made very large to accommodate the asbestos barriers and backs. In installing this type of arrester it is advisable to place it as near as possible to the top of the pole so that the arc may rise unobstructed and thus avoid the likelihood of live wires coming in contact with the horns which, during the operation of the series current, are alive.

Electrolytic Arresters.—Arresters of this class are sometimes called aluminum arresters because of the property of aluminum on which their action depends; that is, *it depends on the phenomenon that a non-conducting film is formed on the surface of aluminum when immersed in certain electrolytes.*

If however, the film be exposed to a higher pressure, it may be punctured by many minute holes, thus so reducing its resistance that a large current may pass. When the pressure is again reduced the holes become resealed and the film again effective.

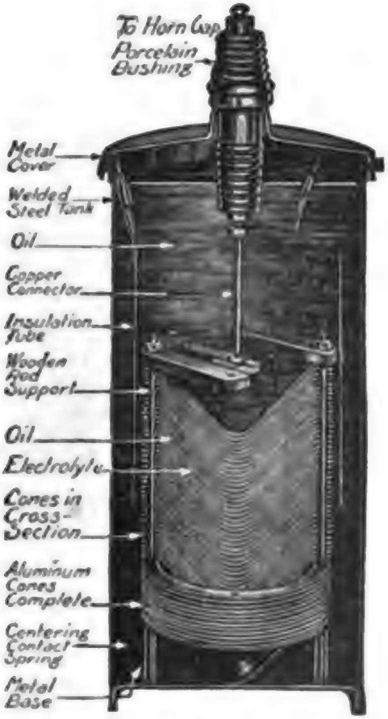

HORNS
GAP
DISCONNECTING POSITION
60°
OPERATING POSITION
NORMAL POSITION
CHARGING POSITION

FIGS. 2,383 and 2,384.—Elevation and plan of General Electric horn gaps and operating stand for high voltage arresters.

In construction, the aluminum arrester consists essentially of a system of nested aluminum cup shaped trays, supported on porcelain and secured in frames of heated wood, arranged in a steel tank.

The system of trays is connected between the line and ground, and between line and line, a horn gap being inserted in the arrester circuit which prevents the arrester being subjected to the line voltage except when in action.

The electrolyte is poured into the cones and partly fills the pace between the adjacent ones. The stack of cones with the lectrolyte between them is then immersed in a tank of oil. The electrolyte between adjacent cones forms an insulation. The oil improves this insulation and prevents the evaporation f the solution.


To Horn Gap
Porcelain Bushing
Metal Cover
Welded Steel Tank
Oil
Copper Connector
Insulation Tube
Wooden Rod Support
Oil
Electrolyte
Cones in Cross-Section
Aluminum Cones Complete
Centering Contact Spring
Metal Base

IG. 2,385.—Cross section of General Electric aluminum (electrolytic) lightning arrester.

A cylinder of insulating material concentric with the cone tack is placed between the latter and the steel tank, the object eing to improve the circulation of the oil and increase the nsulation between the tank and the cone stack. The arrester, s just described consists of a number of cells connected in series.

Ques. Of what does a single cell consist and what are ts characteristics?

Ans. It consists of two of the cone shaped aluminum trays or plates and an electrolyte, which forms a condenser that wil stand about 350 volts before breaking down. When this voltage is exceeded the cell becomes a fairly good conductor of electricity, but as soon as the voltage drops its resistance again resumes a very high value.

Ques. What is the critical voltage?

Ans. The voltage at which the current begins to flow freely.

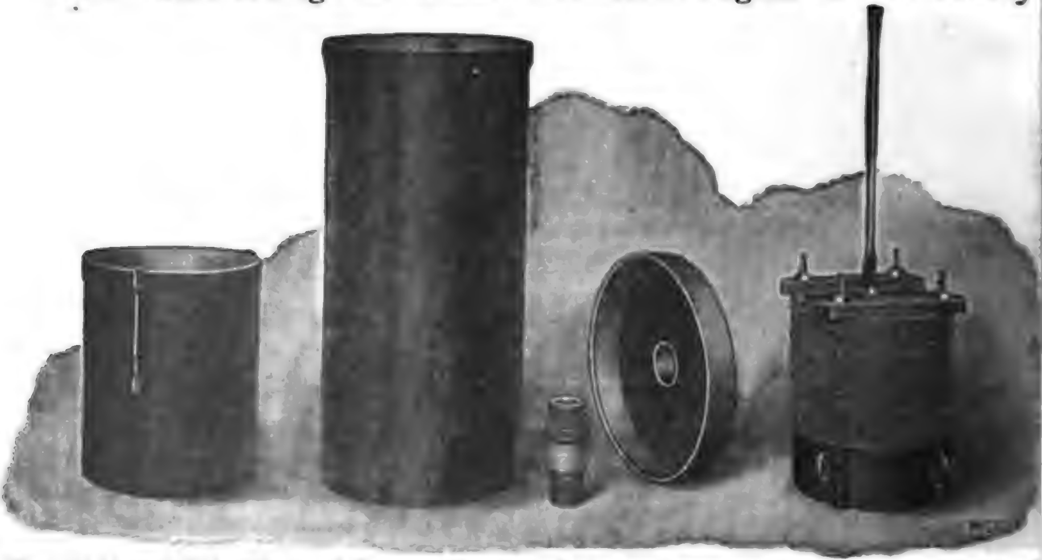


FIG. 2,386 to 2,390.—Parts of General Electric 15,000 volt aluminum lightning arrester, not including horn gaps, etc.

Up to a certain voltage the cell allows an exceedingly low current to flow, but at a higher voltage the current flow is limited only by the internal resistance of the cell, which is very low. A close analogy to this action is found in the well known safety valve of the steam boiler, by which the steam is confined until the pressure rises above a given value, when it is released. On the aluminum plates there are myriads of minute safety valves, so that, if the electric pressure rise above the critical voltage, the discharge takes place equally over the entire surface. It is important to distinguish between the valve action of this hydroxide film and the failure of any di-electric substance.

Ques. When a cell is connected permanently to the circuit what two conditions are involved?

Ans. The *temporary* critical voltage and the permanent *critical voltage.*

For instance, if the cell have 300 volts applied to it constantly, and the pressure be suddenly increased to, say 325 volts, there will be a considerable rush of current until the film thickness has been increased to withstand the extra 25 volts; this usually requires several seconds In this case 325 volts is *the* **temporary** *critical voltage of the cell.*

Similar action will occur at any pressure up to about the **permanent** critical voltage, or *the voltage at which the film cannot further thicken,* and therefore allow a free flow of current.

If the voltage be again reduced to 300 the excess thickness of film will be gradually dissolved, and if it vary periodically between two values, each of which is less than the permanent critical value, the temporary critical voltage will be the higher value. This feature is of great importance as it provides a means of discharging abnormal surges, the instant the pressure rises above the impressed value.

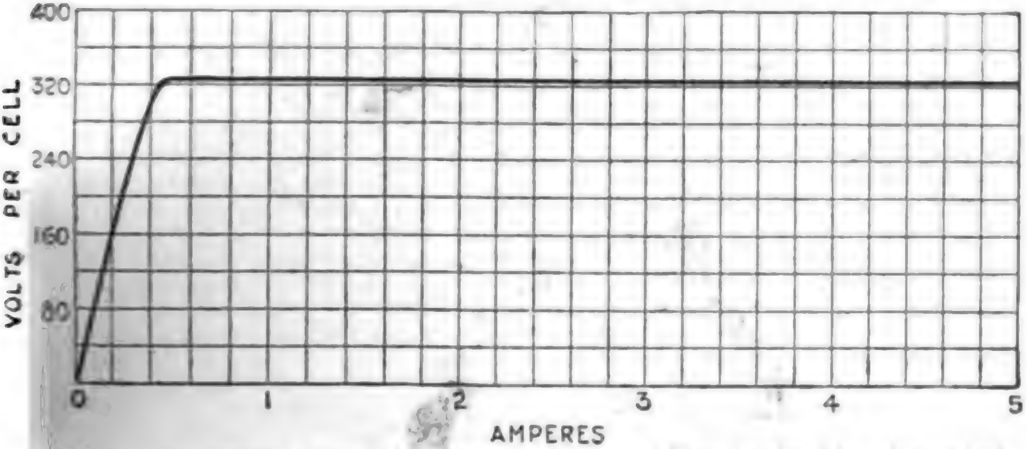


FIG. 2,201.—Volt ampere characteristic curve of a General Electric aluminum (electrolytic) cell on alternating current. The permanent critical voltage is between 335 and 360 volts. With alternating current, the cell acts as a fairly good condenser, and there is not only the leakage through the film, but also a capacity current flowing into the cell. The phase of this current, then, is nearly 90 degrees ahead of the pressure and represents a very low energy factor.

Ques. How is the number of cell required for a given circuit determined?

Ans. The number required for a given operating voltage is determined by allowing about 250 to 300 volts per cell.

Ques. In putting cells in commission how is the electrolyte introduced?

Ans. It is poured into the aluminum trays and the overflow drawn off at the bottom of the tank.

Ques. Describe the further operations in putting cells in commission.

Ans. After putting in the electrolyte it is allowed to stand for a few days until part has evaporated, then the oil is poured over the surface to prevent further evaporation.

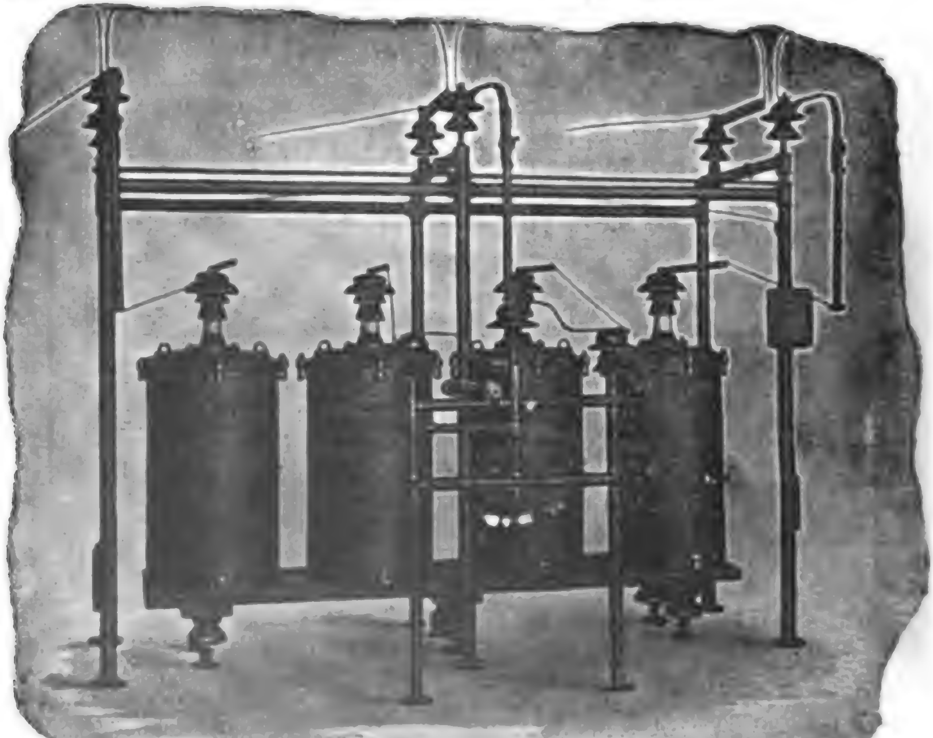


FIG. 2,392.—Westinghouse electrolytic lightning arrester, for three phase ungrounded neutral service, 25,000 maximum voltage. These arresters are designed for the protection of alternating current circuits from all kinds of static disturbances. They have been standardized for installation on three phase circuits of voltages of 2,200 to 110,000. They cannot be used for voltages of less than 13,500. For voltages below this the horn gaps cannot, with safety, be set close enough together, out of doors, to take advantage of the freedom of discharge of the electrolytic element. If the horn gaps be set too close together they may be short circuited by rain. A shelter should be built for arresters of 13,500 volts and below for their protection when installed outside.

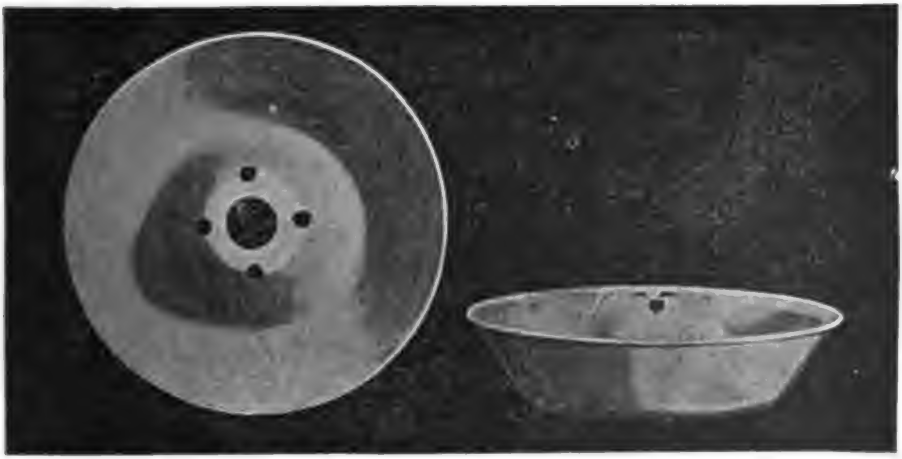
Ques. What action takes place when the trays stand in the electrolyte and cell is disconnected from the circuit?

Ans. Part of the film deteriorates.

Ques. What is the nature of the film?

Ans. The film is composed of two parts, one of which is hard and insoluble, and apparently acts as a skeleton to hold the more soluble part. The action of the cell seems to indicate that the soluble part of the film is composed of gases in a liquid form.

Ques. What action takes place when a cell which has stood for some time disconnected, is reconnected to the circuit?



FIGS. 2,393 and 2,394.—Aluminum trays for Westinghouse electrolytic lightning arresters.

Ans. There is a momentary rush of current which reforms the part of the film which has dissolved.

This current rush will have increasing values as the intervals of rest of the cell are made greater.

Many electrolytes have been studied, but none has been found which does not show this dissolution effect to a greater or lesser extent.

If the cell has stood disconnected from the circuit for some time, especially in a warm climate, there is a possibility that the initial current rush will be sufficient to open the circuit breakers or oil switches. This current rush also raises the temperature of the cell, and if the temperature rise be great, it is objectionable.

When the cells do not stand for more than a day, however, the film dissolution and initial current rush are negligible.

Ques. What is the object of using horn gaps on electrolytic arresters?

Ans. The use is threefold: 1, it prevents the arrester being subjected continually to the line voltage: 2, acts as a disconnecting switch to disconnect the arrester from the line for repairs, etc., and 3, acts as a connecting switch for charging.

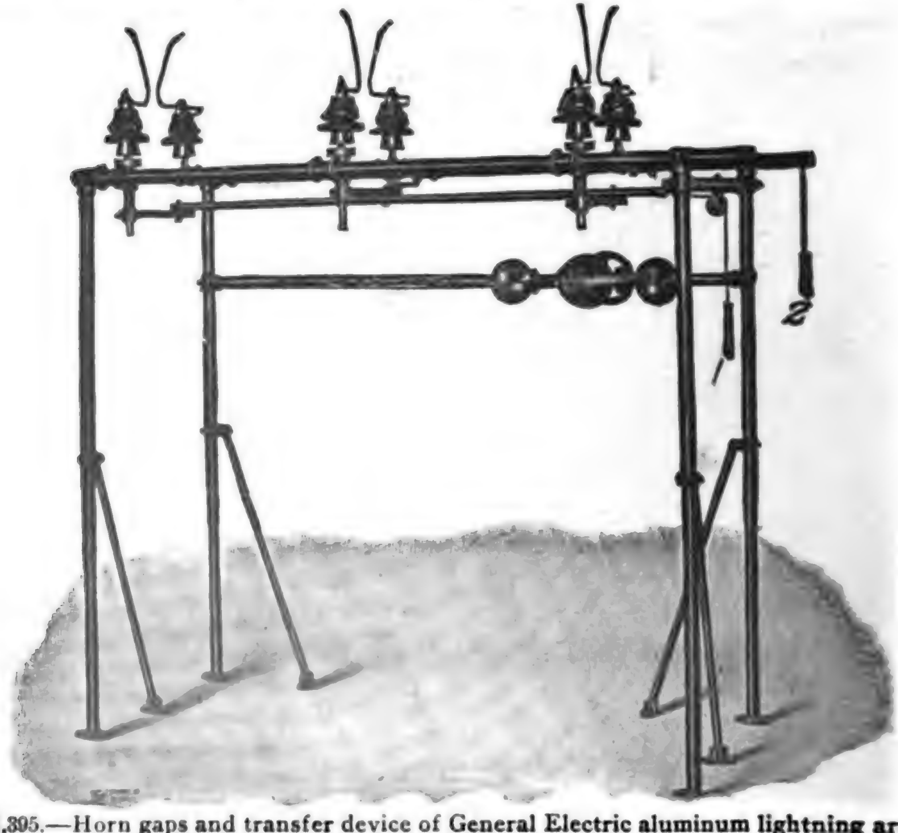


FIG. 2,395.—Horn gaps and transfer device of General Electric aluminum lightning arrester for 12,500 volt non-grounded neutral circuit. The object of the transfer device is to provide a means for interchanging the ground stacks with one of the line stacks of cones during the charging operation so that the films of all the cells will be formed to the same value. The transfer device consists of a rotating switch which may be turned 180 degrees, thus interchanging the connections of the ground stack and one of the line stacks. For arresters up to 27,000 volts the device is mounted with three insulators on the pipe frame work, and is operated by a hand wheel; for arresters of higher voltage, the transfer device is mounted directly over the tanks and is operated by bevel gears and hand wheel.

Charging of Electrolytic Arresters.—In electrolytic arresters all electrolytes dissolve the film when the arrester is on open circuit, the extent of the dissolution depending upon the length of time the film is in the electrolyte, and upon its temperature. It is therefore necessary to *charge* the cells from time to time and thus prevent the dissolution and consequent rush of current which would otherwise occur when the arrester discharges.

Ques. Describe the charging operation for arresters with grounded circuits.

Ans. It consists in simply closing simultaneously the three horn gaps so that the full pressure across the cells causes a small charging current to flow and form the films to their normal condition.

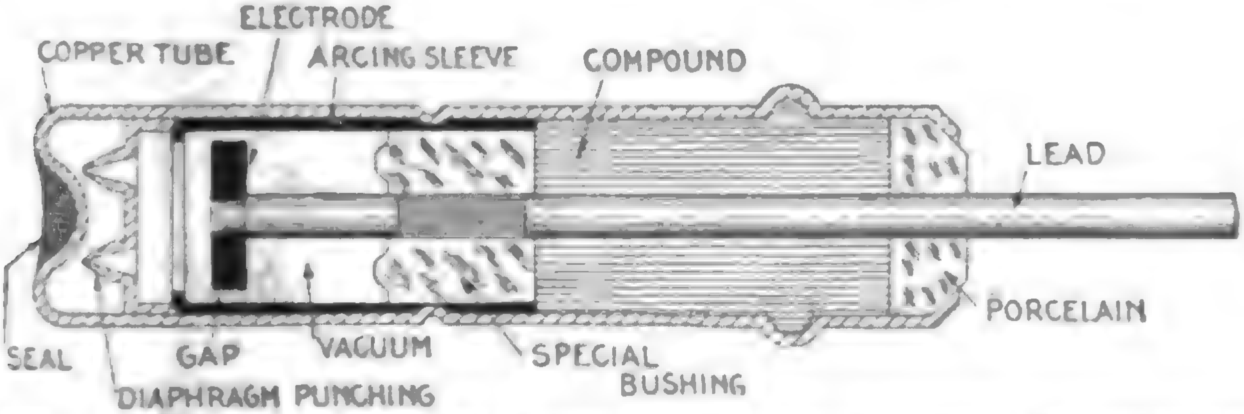


FIG. 2,[illegible].—Sectional view of General Electric **vacuum tube arrester** for railway signal circuits. **The arrester** *is essentially a gap in a vacuum.* **In construction**, the gap is formed between the inner wall of a drawn metal shell and a disc electrode mounted concentric with it. **The electrode** is supported on a brass rod which serves as the lead in connection, and has ample current carrying capacity. The electrode system is insulated from the tube and rigidly supported in position by a bushing made of vitreous material. The bushing does not form the vacuum seal, that being made by a special compound. **The open end of the tube** is finally closed by a porcelain bushing. The tube is exhausted in a special machine which solders a small hole in the end after the vacuum has been established. The possibility of solder entering the active part of the vacuum space is prevented by a diaphragm punching, and both the electrode and the lining of the tube are of non-arcing metal. **The arrester has a spark pressure of** from 350 to 600 volts direct current, and an equivalent needle gap of about .005 inch. The arrester will not stand a continuous flow of current due to excessive heating, hence if there be a possibility of this due to high pressure crosses, fuses should be used. R. R. S. A. standard terminals are used.

Ques. Describe the charging operation for arresters for non-grounded circuits.

Ans. First, the horn gaps are closed for five seconds and opened again to normal position, thus charging the cells of the three line stacks. Second, with the horn gaps still in normal position, the position of the transfer device is reversed and the horn gaps are again closed for five seconds and returned to the normal position.

The complete charging operation takes but a few moments and should be performed daily. The operation is valuable, not only in keeping the films in good condition, but also in giving the operator some idea of the condition of the arrester by enabling him to observe the size and color of the charging spark.

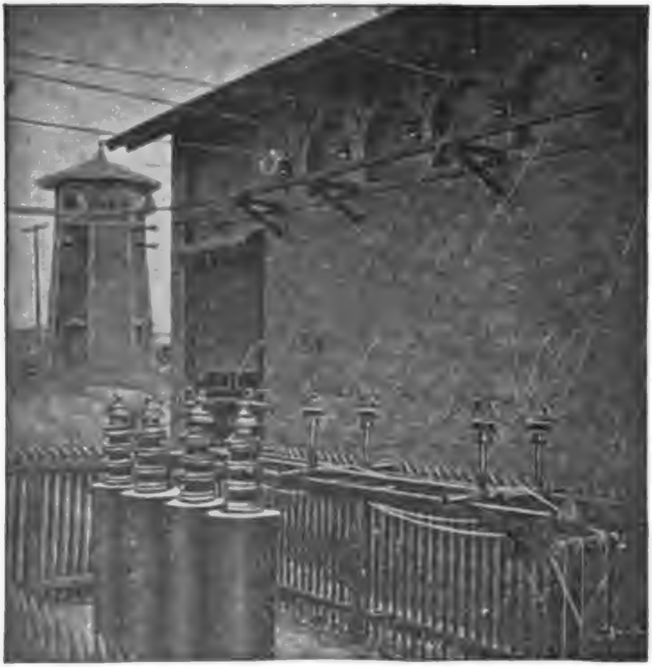


FIG. 2,397.—Highland Park sub-station, Charlotte, N. C., showing old lightning arrester tower on the left and General Electric aluminum (electrolytic) cell lightning arrester and horn gaps in foreground.

Grounded and Non-grounded Neutral Circuits.—It is important to avoid the mistake of choosing an arrester for a thoroughly grounded neutral when the neutral is only partially grounded, that is, grounded through an appreciable resistance. Careful consideration of this condition will make the above statement clear.

In an arrester for a grounded neutral circuit, each stack of cones normally receives the neutral pressure when the arrester discharges, but if a phase become accidently grounded, the line voltage is thrown across each of the other stacks of cones until the circuit breaker opens the circuit. The line voltage is 173 per cent. of the neutral or normal operating voltage of the cells and therefore about 150 per cent. of the permanent critical voltage of each cell. This means that when a grounded phase occurs, this 50 per cent. excess pressure is short circuited through the cells until the circuit breaker opens.

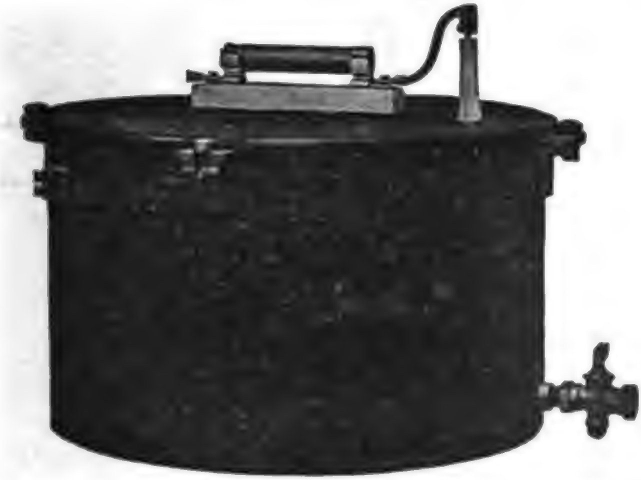


FIG. 2,398.—Westinghouse **electrolytic station lightning arrester** for direct current up to 1,500 volts consists of a tank of oil in which are placed, on properly insulated supports, a nest of cup shaped aluminum trays. The spaces between the trays are filled with electrolyte, a sufficient quantity for one charge being furnished with each arrester. The top tray is connected with the line through a 60 ampere fuse, and the bottom tray is connected to the tank which is thoroughly grounded by means of a lug. The fuse is of the enclosed type and mounted on the cover of the arrester. **A small charging current** flows through the trays continuously and keeps the films on the trays built up, so that no charging is required. This charging current is not, however, of sufficient value to raise the temperature appreciably. The immersed area of each tray is 100 square inches. The shape and the arrangement of the trays is such that any gases generated by the discharge can pass out readily without disturbing the electrolyte between the trays.

The amount of energy to be dissipated in the arrester depends upon the kilowatt capacity of the generator, the internal resistance of the cells, and the time required to operate the circuit breakers. It is evident that the greater the amount of resistance in the neutral, the longer will be the time required for the circuit breakers to operate. Therefore, in cases where the earthing resistance in the neutral is great enough to prevent the automatic circuit breakers opening practically instantaneously, an arrester for a non-grounded neutral system should be installed.

Figs. 2,399 to 2,401.—Westinghouse ground fittings. Fig. 2,399, ground plate; fig. 2,400, ground point; fig. 2,401, cap. The ground plate consists of a circular piece of cast iron, 12 inches in diameter, 1⅜ inches thick with a ¾ inch pipe tap in center to connection to arrester. The surface is increased by means of corrugations, as shown in the accompanying illustrations, to 461 square inches, affording ample contact with the earth and enabling it to take care of all discharges through the arrester. The plate should preferably be buried at the foot of the pole so that the ground wire runs to it in a straight line from the arrester. Care should, of course, be taken to see that the earth in which the plate is buried is damp. If the ground wire be placed within the pipe leading to the ground plate it should be soldered to a cap at the top of the pipe to eliminate the inductive effect due to the wire being surrounded by iron. A simple and effective method of securing a good ground is by means of an iron pipe with a malleable iron point having a dipped galvanized finish, and a brass cap with a lug for soldering the ground wire. The pipe may be driven into the earth, or if it be too hard to permit driving, a hole may be dug and the pipe placed therein. It should extend from eight to ten feet above and below the earth to secure, respectively, a good ground and prevent any tampering with the ground wire. Should it be desired to make use of a longer pipe which would be inconvenient to drive into the earth, two pieces can be used and connected together by a coupling. The brass cap and malleable iron point are tapped for use with ¾ inch pipe.

Ground Connections.—In all lightning arrester installations it is of the utmost importance to make proper ground connections, as many lightning arrester troubles can be traced to bad grounds. It has been customary to ground a lightning arrester by means of a large metal plate buried in a bed of charcoal at a depth of six or eight feet in the earth.

A more satisfactory method of making a ground is to drive a number of one inch iron pipes six or eight feet into the earth surrounding the station, connecting all these pipes together by means of a copper wire or, preferably, by a thin copper strip. A quantity of salt should be placed around each pipe at the surface of the ground and the ground should be thoroughly moistened with water. It is advisable to connect these pipes to the iron framework of the station, and also to any water mains, metal flumes, or trolley rails which are available.

FIGS. 2,402 to 2,404.—General Electric **magnetic blow out arrester** for use on railways. **It consists of** *an adjustable spark gap in series with a resistance.* **Part of the resistance** is in shunt with a blow out coil, between the poles of which is the spark gap. The parts are mounted in a strong, porcelain box, which, for car and pole use, is in turn mounted in a substantial asbestos lined, wooden box. **In operation**, when the lighting pressure comes on the line, it causes the spark gap to break down and a discharge occurs through the gap and the resistance rod to ground. Part of the current shunts through the blow out coil producing a strong magnetic field across the spark gap. The magnetic field blows out the discharge arc and restores normal conditions. The resistance is only 60 ohms (for 500 volt rating work), and the spark gap only one-fortieth of an inch (.025 in.).

The following suggestions are made for the usual size station.

1. Place three pipes equally spaced near each outside wall, making twelve altogether, and place three extra pipes spaced about six feet apart at a point nearest the arrester.

2. Where plates are placed in streams of running water, they should be buried in the mud along the bank in preference to being laid in the stream. Streams with rocky bottoms are to be avoided.

3. Whenever plates are placed at any distance from the arrester, it is necessary also to drive a pipe into the earth directly beneath the arrester, thus making the ground connection as short as possible. Earth plates at a distance cannot be depended upon. Long ground wires in a station cannot be depended upon unless a lead is carried to the parallel grounding pipes installed as described above.

4. As it is advisable occasionally to examine the underground connections to see that they are in proper condition, it is well to keep on file exact plans of the location of ground plates, ground wires and pipes, with a brief description, so that the data can be readily referred to.

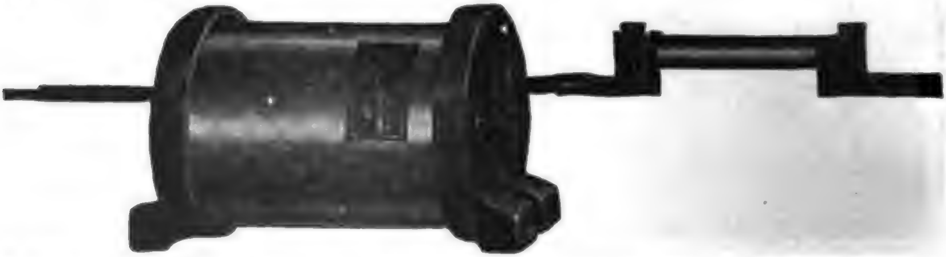


FIG. 2,405.—General Electric **magnetic blow** out arrester for line use. **It consists** essentially *of a small spark gap which is in series with a resistance, and between the poles of a magnet.* **The operation** is similar to that of the arrester shown in figs. 2,402 to 2,404, but the magnet is a permanent magnet instead of an electromagnet. The spark gap and the magnet are mounted within porcelain blocks in such a way that the discharge arc is blown by the magnet through an arc chute and a cooling grid which is also held by the porcelain. The **cooling grid** in the arc chute materially assists the magnet in extinguishing the discharge arc, giving the arrester a high arc rupturing quality. **The series rod** is carborundum and is connected externally to the other portion of the arrester. The arrester is self-contained.

5. From time to time the resistance of these ground connections should be measured to determine their condition. The resistance of a single pipe ground in good condition has an average value of about 15 ohms. A simple and satisfactory method of keeping account of the condition of the earth connections is to divide the grounding pipes into two groups and connect each group to the 110 volt lighting circuit with an ammeter in series.

Choke Coils.—A lightning discharge is of an oscillatory character and possesses the property of self-induction, accordingly it passes with difficulty through coils of wire. Moreover, the frequency of oscillation of a lightning discharge being much greater than that of commercial alternating currents, a coil can readily be constructed which will offer a relatively high resistance to the passage of lightning and at the same time allow free passage to all ordinary electric currents.

Opinions on the design of choke coils for use with lightning arresters vary considerably. Some engineers recommend the use of very large choke coils, but while large choke coils of high inductance do choke back the high frequency currents better than smaller coils of less inductance, they cost more, and under many conditions they are a menace to the insulation unless the lightning arresters be installed on both sides of them.

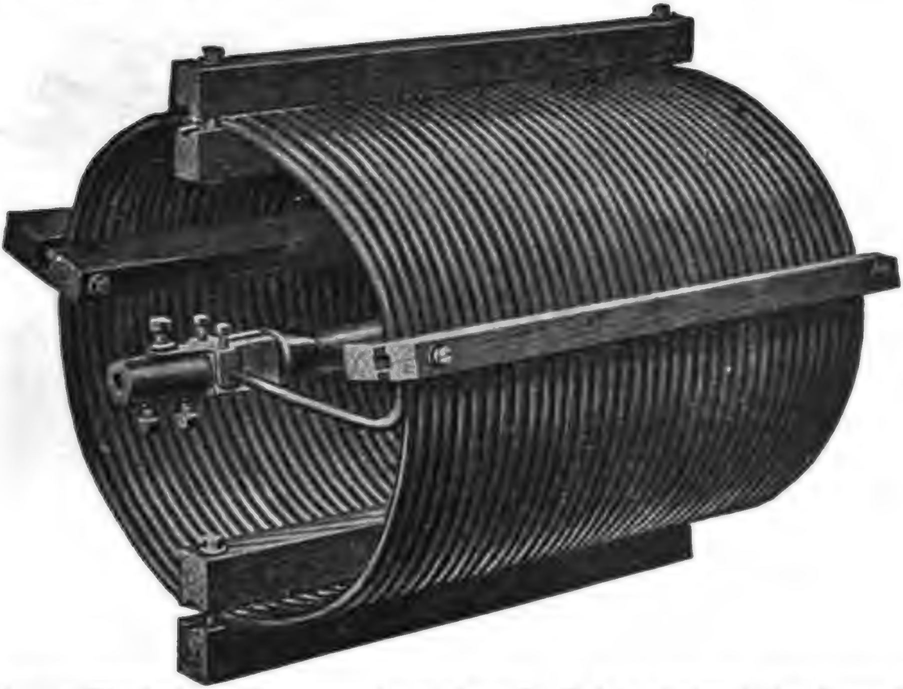


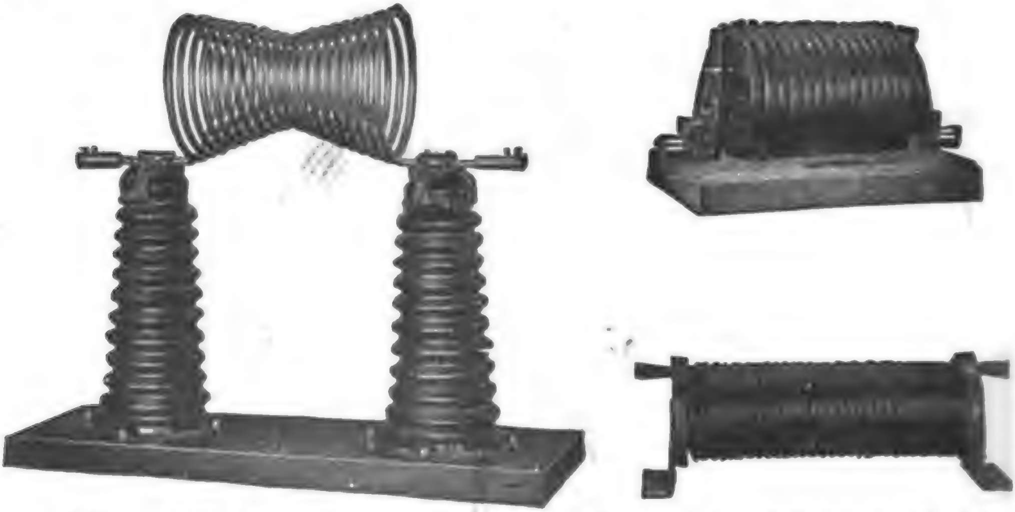
FIG. 2,406.—Westinghouse line suspension choke coil. It is so designed that it can be inserted directly in the transmission line wire or in the station wiring and held in position therein by the tension of the line or station wires. Because of the fact that no insulators are required, solely to support this choke coil, and that it can be installed in either a vertical or a horizontal position it can often be utilized effectively in power and substation layouts. Terminals, each having a ½ inch round hole, to accommodate the conductors are provided at each end of the coil. Three square headed binding screws are supplied which clamp the conductors in position. The coil is provided with a strain insulator, so arranged within the coil at its axis, that it assumes any mechanical tension transmitted from the conductors. No mechanical tension reaches the turns of the choke coil proper. In construction, the choke coil is made in but one size having a current carrying capacity of 200 amperes and is suitable for a voltage of 2,000 to 22,000. For higher voltages than 22,000, several choke coils are connected in series. One coil is used for each 22,000 volts or fraction thereof, of the pressure between the wires of the circuit. **Application:** This type of choke coil may be used for alternating current service for the entire range from 22,000 to 110,000 volts. It may be used on transformers, but is not recommended for the protection of generators.

Part of the functions of the choke coil are performed by the end turns of a transformer and extra insulation is invariably installed in al power transformers built in recent years.

The choice of choke coils must be influenced by the condition o insulation in the transformers as well as by the cost, pressure regulation and nature of the lightning protection required.

Ques. What are the primary objects of a choke coil?

Ans. To hold back the lighting disturbance from the circuit apparatus during discharge, and to lower the frequency o the oscillation so that whatever charge gets through the choke coil will be of a frequency too low to cause serious pressure drop around the first turns of the end coil in either alternator o transformer.



Figs. 2,407 to 2,409.—General Electric choke coils. Fig. 2,407, hour glass choke coil, 45,000 volts; fig. 2,408, low voltage choke coil, 6,600 volts; fig. 2,409, low voltage choke coil 4,600 volts.

If there be no arrester, the choke coil cannot perform the first function, accordingly a choke coil is best considered as an auxiliary to an arrester.

Ques. What is the principal electrical condition to be avoided with a choke coil?

Ans. Resonance. The coil should be so arranged that i continual surges be set up in the circuit, a resonant voltage due to the presence of the choke coil cannot build up at the transformer or generator terminals. This factor is a menace to the insulation. Another way of stating the condition is as follows: So arrange the choke coil as not to prevent surges, originating in a transformer, passing to the arrester.

Ques. What is another electrical condition to be avoided and why?

Ans. Internal static capacity between adjacent turns

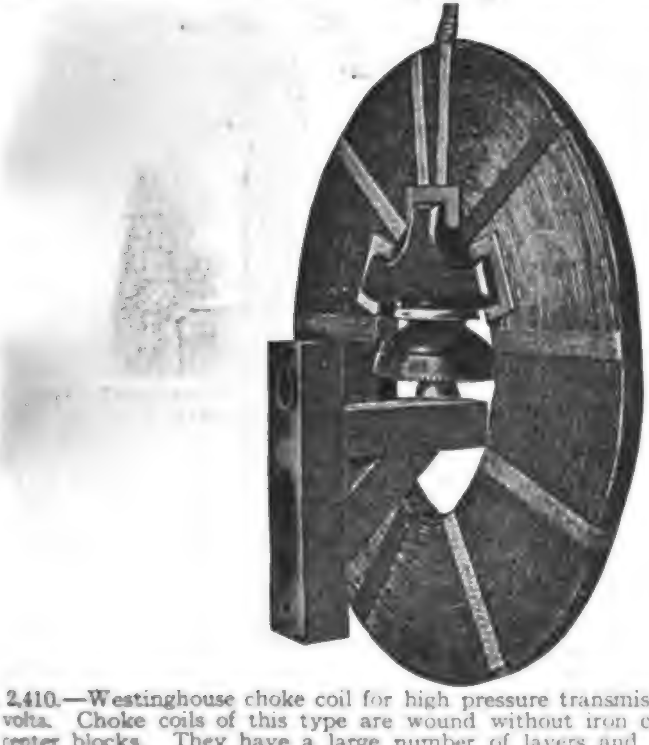


FIG. 2,410.—Westinghouse choke coil for high pressure transmission circuits, 2,200 to 25,000 volts. Choke coils of this type are wound without iron cores on circular or elliptical center blocks. They have a large number of layers and few turns per layer (except those made for small currents, they usually have one turn per layer), which give the best condition for insulating and cooling. They are air cooled, heavily insulated and have a line lead at the top, as shown. Choke coils are designed to prevent the short circuits sometimes caused by the local concentration of pressure such as may be produced by a lightning discharge. They limit, to some extent, an abnormal rise of pressure on the apparatus by delaying the advance of a static wave from the line and thus give the arrester more time to act. The disturbance caused by a lightning flash passes along the line in the form of a surge or "tidal wave." If this wave pass a choke coil, it is flattened out, and if the coil be of sufficient power, becomes practically harmless. It is evident, however, that the choke coil receives the full force of the wave, and that, consequently, it must be heavily insulated; moreover, the choke coil must not overheat under load, nor introduce into the circuit excessive inductive resistance.

of the choke coil, because this lowers the effectiveness of the coil.

Ques. What is the object of making choke coils in the form of an hour glass?

Ans. To prevent sagging between the supports.

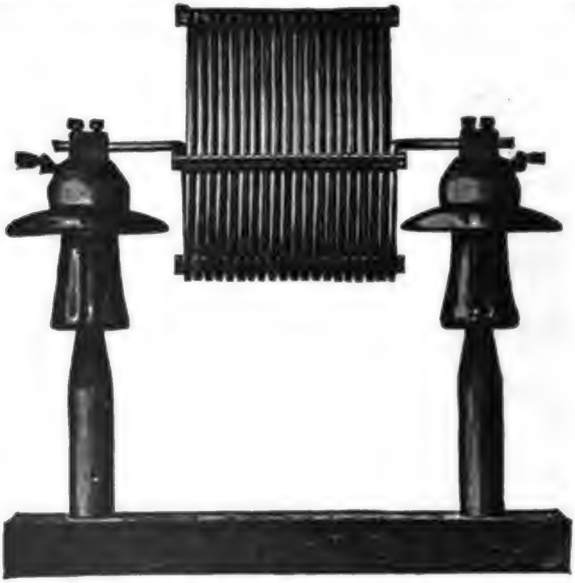


FIG. 2,411.—Westinghouse **air cooled choke coil** particularly suitable for outdoor use. **The method of mounting** is such that insulation for any desired voltage is readily obtained with the same type of porcelain, and mounting in any position is possible. **The coil** is a helix of aluminum rod, about 15 inches in diameter and containing about 30 turns. Bracing clamps are provided to give mechanical strength to the helix, and the rod used is of sufficient diameter to carry 200 amperes. The coil is supported on two insulating columns made up of porcelain insulators, which, except for the end pieces, are interchangeable. The number of insulators used in the columns depends on the voltage of the circuit in which the coil is to be used. The apparatus can be mounted in any position convenient for the wiring, on floor, wall, or ceiling. **It is intended principally** *for the protection of transformers.* Where greater reactance than is afforded by a single coil is desired on the higher voltage circuits, it is recommended that two or more coils be connected in series, one coil being used for each 22,000 line voltage. This coil should not be used for generators. The insulating columns are supported on substantial cast iron blocks on wooden bases.

Ques. How are choke coils cooled?

Ans. By air, or by oil.

Ques. For what service are oil cooled choke coils used?

Ans. On circuits of pressures above 25,000 volts, choke coils immersed in oil, as are transformer coils, have advantages in that the coil is amply insulated not only from the ground ut against side flash, and that copper of comparatively small ection may be used without undue heating.

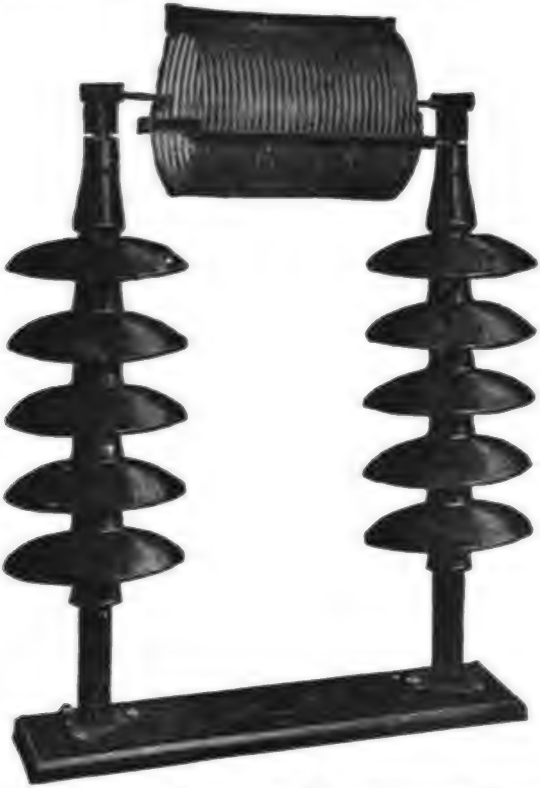


Fig. 2,412.—Westinghouse **air cooled choke coil**, for voltages of from 2,200 to 110,000. **In construction**, the coils are made of aluminum rod wound into a helix of about 15 inches in diameter and having 20 turns. The helix is supported on two insulators. For mechanical reasons it is necessary to have the aluminum rod of sufficient size to secure rigidity, consequently every coil has a capacity of 200 amperes and may be used on any circuit up to that capacity. **The coils** are insulated according to the standard practice for disconnecting switches, the insulators being mounted on wooden pins supported by a wooden base. This apparatus can be mounted in any position. The wiring of a station or sub-station is facilitated because the protection may be placed so as to simply form part of the wiring. The coils are symmetrical so that it is immaterial which end is connected to the line or to the apparatus.

"Static" Interrupters.—A static interrupter is a *combination of a choke coil and a condenser*, the two being mounted together and placed in a tank and oil insulated.

It is used on high pressure circuits and its function is to so delay the erroneously called "static" wave in its entry into the transformer coil, that a considerable portion of the latter will become charged before the terminal will have reached full pressure.

A choke coil alone sufficiently powerful to accomplish thi would be too large and costly on very high pressure and woul interfere with the operation of the system.

Ques. How is the condenser and choke coil connected?

Ans. The condenser is connected between the line and groun behind the choke coil near the apparatus to be protected a shown in fig. 2,413.

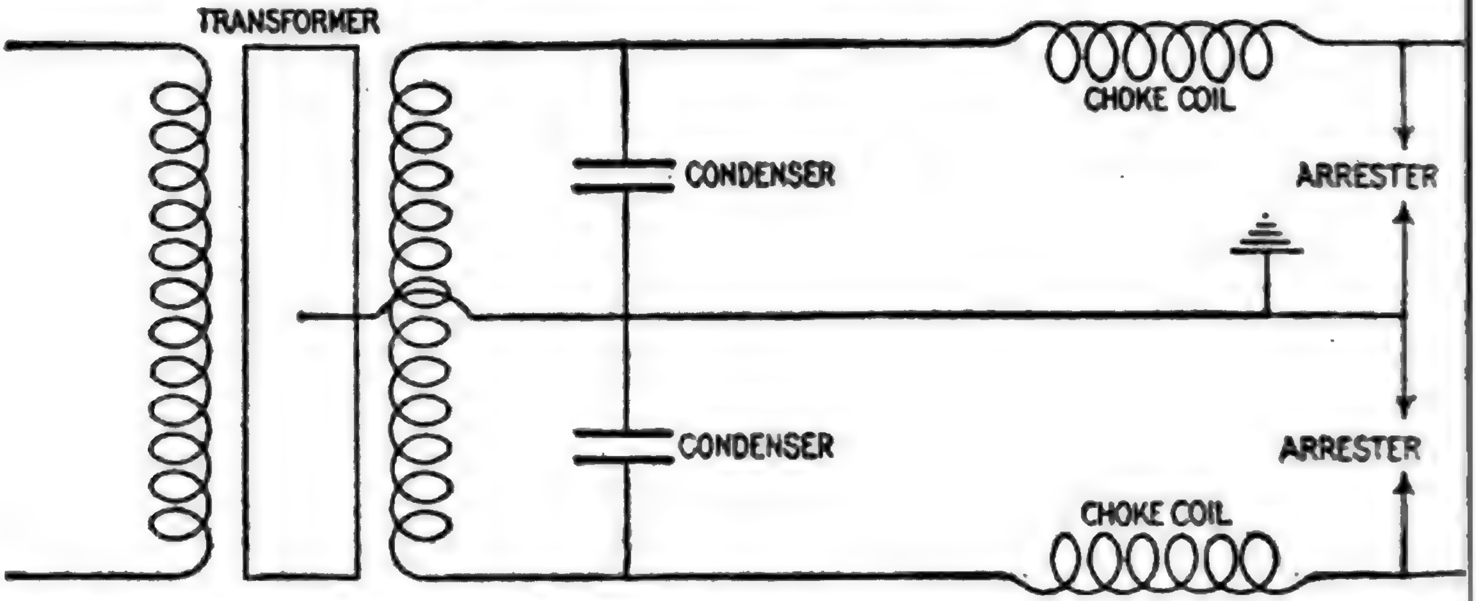


FIG. 2,413.—Diagram showing connections of static interrupter for protecting a transformer.

Ques. What is the effect of the condenser?

Ans. The condenser, which has a very small electro-stati capacity, has no appreciable effect upon the normal operation but a very powerful effect upon the static wave on account o its extremely high frequency.

CHAPTER LX

REGULATING DEVICES

Regulation of Alternators.—Practically all the methods emloyed for regulating the voltage of direct current dynamos nd circuits, are applicable to alternators and alternating current ircuits. For example: in order that they shall automatically aintain a constant or rising voltage with increase of load, lternators are provided with composite winding similar to the ompound winding of direct current dynamos, but since the lternating current cannot be used directly for exciting the eld magnets, an accessory apparatus is required to rectify or change it into direct current before it is used for that purpose.

It is a fact, however, that composite wound alternators do ot regulate properly for inductive as well as non-inductive ads.

In order to overcome this defect compensated field alternators ave been designed which automatically adjust the voltage for ll variations of load and lag. These machines have already een described.

Alternating Current Feeder Regulation.—With slight odification, the various methods of feeder regulation employed ith direct current, may be applied to alternating current distriution circuits. For instance, if a non-inductive resistance be troduced in any electric circuit, the consequent drop in voltage will be equal to the current multiplied by the resistance. Ther fore, feeder regulation by means of rheostats is practically th same in the case of alternating current as in that of dire current. In the case of the former, however, the effect of sel induction may also be utilized to produce a drop in voltag In practice, this is accomplished by the use of self-inductio coils which are commonly known as reactance coils.

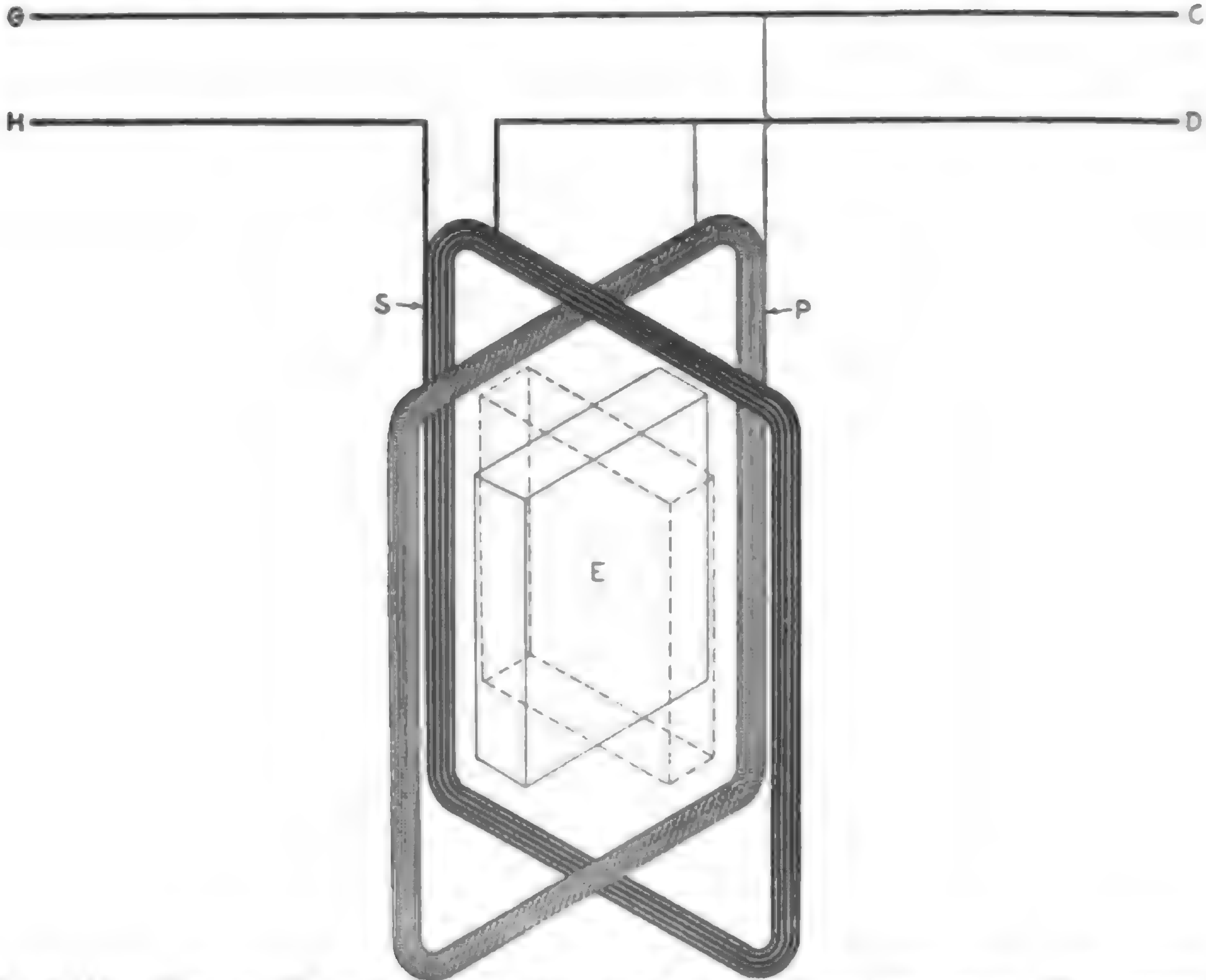


FIG. 2,414.—Diagram *illustrating the principle of* **induction voltage regulators. The prima coil P,** *consisting of many turns of fine wire,* is connected across the main conductors C a D, coming from the alternator. **The secondary coil S,** *consisting of a few turns of hea wire,* is connected in series with the conductor D. The laminated iron core E, mount within the coils, is capable of being turned into the position shown by the dotted line When the core is vertical, the magnetic lines of force produced in it by the primary co induces a pressure in the secondary coil which aids the voltage; when turned to t position indicated by the dotted lines, the direction of the magnetic lines of force a reversed with respect to the secondary coil and an opposing pressure will be produc therein. Thus, by turning the core, the pressure difference between the line wires and H, can be varied so as to be higher or lower than that of the main conductors and D. Regulators operating on this principle may be used for *theatre dimmers,* as co trollers for series lighting, and also to adjust the voltage or the branches of unbalanc three wire single phase and polyphase systems.

Application of Induction Type Regulators.—In supplying lighting systems, where the load and consequently the pressure drop in the line increases or decreases, it becomes necessary to raise or lower the voltage of an alternating current, in order to regulate the voltage delivered at the distant ends of the system. This is usually accomplished by means of *alternating current regulators or induction regulators.* A devise of this kind is essentially a transformer, the primary of which is excited

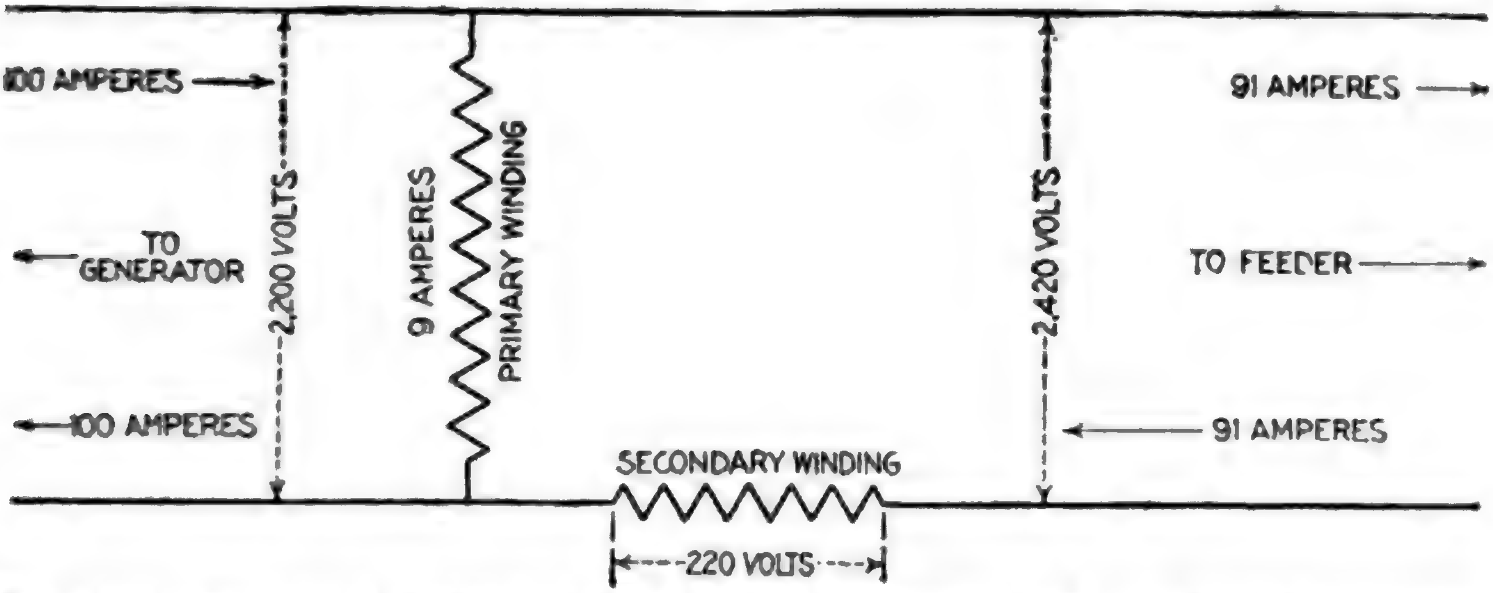

100 AMPERES
TO GENERATOR
100 AMPERES
2,200 VOLTS
9 AMPERES
PRIMARY WINDING
SECONDARY WINDING
220 VOLTS
2,420 VOLTS
91 AMPERES
TO FEEDER
91 AMPERES

FIG. 2,415.—Diagram of induction regulator **raising the voltage** 10%. In the diagram an alternator is supplying 100 amperes at 2,200 volts. The regulator raises the feeder pressure to 2,420 volts, the current being correspondingly reduced to 91 amperes, the other 9 amperes flowing from the alternator through the primary of the regulator, back to the alternator.

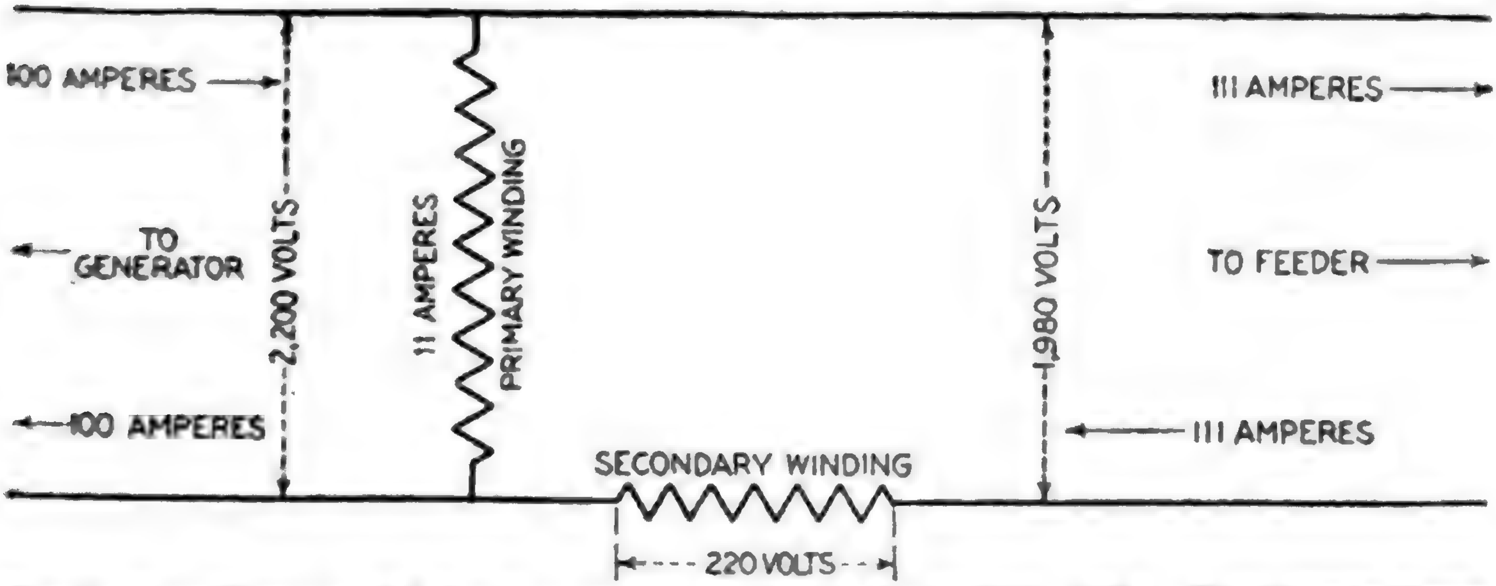

100 AMPERES
TO GENERATOR
100 AMPERES
2,200 VOLTS
11 AMPERES
PRIMARY WINDING
SECONDARY WINDING
220 VOLTS
1,980 VOLTS
111 AMPERES
TO FEEDER
111 AMPERES

FIG. 2,416.—Diagram of induction regulator **lowering the voltage** 10%. The diagram shows the regulator lowering the feeder pressure to 1,980 volts with an increase of the secondary current to 111 amperes, the additional 11 amperes flowing from the feeder, through the primary back to the feeder.

Digitize

by being connected directly across the circuit, while the secondary is in series with the circuit as shown in fig. 2,414. By this method the circuit receives the voltage generated in the secondary.

Ques. Name two types of pressure regulator.

Ans. The induction regulator, and the variable ratio transformer regulator.

Ques. Of what does an induction regulator consist?

Ans. It consists of a primary winding or exciting coil, a secondary winding which carries the entire load current.

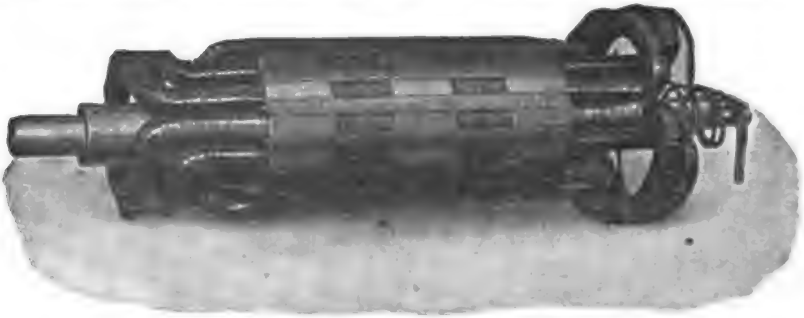


FIG. 2,417.—Moving element or **primary** of Westinghouse motor operated single phase induction regulator. It consists of a core of punchings built up directly on the primary shaft and carrying the primary winding, which is divided into four coils. The primary coils are machine wound and the layers of the winding are separated from each other by heavy insulating material in addition to the cotton covering of the inductors. The complete coils are insulated and impregnated with insulating compound before being placed in the slots. The coils are held in position by fibre wedges.

The primary is wound for the full transmission voltage, and is connected across the line, while the secondary is connected in series with the line.

Ques. What is its principle of operation?

Ans. When the primary coil is turned to various positions the magnetic flux sent through the secondary coil varies in value, thereby causing corresponding variation in the secondary voltage, the character of which depends upon the value and direction of the flux.

Ques. What is the effect of turning the secondary coil to a position at right angles with the primary coil?

Ans. The primary will not induce any voltage in the secondary, and accordingly it has no effect on the feeder voltage.

Ques. What is this position called?

Ans. The neutral position.

Ques. What are the effects of revolving the primary coil from the neutral position first in one direction then in the other?

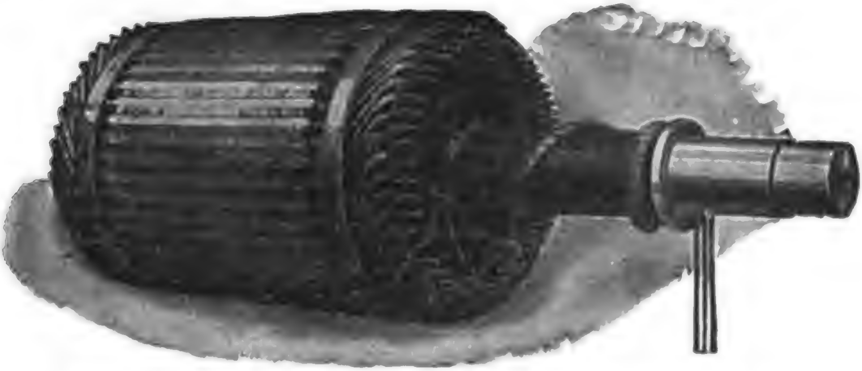


FIG. 2,418.—Moving element or primary of Westinghouse motor operated polyphase induction regulator.

Ans. Turning the primary in one direction increases the voltage induced in the secondary, thus increasing the feeder voltage like the action of a booster on a direct current circuit while turning the primary in the opposite direction from the neutral position, correspondingly decreases the feeder voltage.

Ques. It was stated that for neutral position the primary had no effect on the secondary; does the secondary have any effect on the feeder voltage?

Ans. The secondary tends to create a magnetic field of its own self-induction, and has the effect of a choke coil.

Ques. How is this tendency overcome?

Ans. The primary is provided with a short circuited winding, placed at right angles to the exciting winding. In the neutral position of the regulator, this short circuited winding acts like the short circuited secondary of a series transformer, thus preventing a choking effect in the secondary of the regulator.

Ques. What would be the effect if the short circuited winding were not exployed?

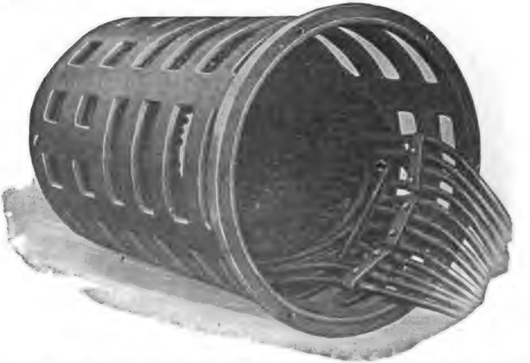


FIG. 2,419.—Top end of stationary element or **secondary** of Westinghouse polyphase induction regulator; view showing leads. The secondary is built up in a short skeleton frame with brackets for the rotor bearings bolted to the frame and the top cover bolted to the top brackets. In assembling the secondary, the punchings are stacked loosely in the skeleton frame and an expanding building mandrel placed inside the punchings and expanded, thereby truing up the latter before they are finally compressed and the end plates keyed in position. Then, prior to removing the mandrel a finishing cut is taken on the surface of the frame to which the bearing brackets are attached, and as the top cover and brackets are also accurately machined the alignment of the primary with the secondary is almost perfect, thus reducing to a minimum the tendency to develop vibration and noise.

Ans. The voltage required to face the full load current through the secondary would increase as the primary is turned away from either the position of maximum or minimum regulation, reaching its highest value at the neutral position.

The short circuited winding so cuts down this voltage of self-induction that the voltage necessary to force the full load current through the secondary when the regulator is in the neutral position is very little more than that necessary to overcome the ohmic resistance of the secondary.

Ques. What effect is noticeable in the operation of a single phase induction regulator?

Ans. It has a tendency to vibrate similar to that of a single phase magnet or transformer.

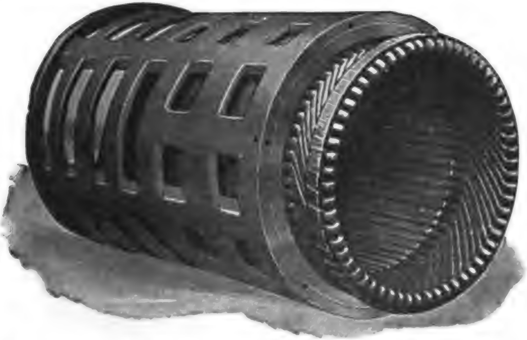


FIG. 2,420.—Bottom end of stationary element or **secondary** of Westinghouse polyphase induction regulator.

Ques. Why?

Ans. It is due to the action of the magnetizing field varying in strength from zero to maximum value with each alteration of the exciting current, thus causing a pulsating force to act across the air gap, which tends to cause vibration when the moving part is not in perfect alignment.

Ques. Explain the effect produced by bad alignment?

Ans. If the bearings of the primary be not in perfect alignment with the bore of the secondary, thereby making the air gap on one side smaller than that on the other, the crowdir over of the flux to the smaller air gap will cause an intermitter pull in that direction, which will develop vibration unless tl primary bearings are tight and the shaft sufficiently stiff t withstand the pull.

Ques. Upon what does the regulator capacity for ar given service depend?

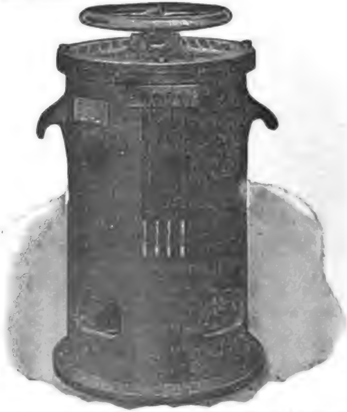


FIG. 2,421.—Westinghouse two kw., hand operated, air cooled induction regulator for testir purposes.

Ans. It depends upon the range of regulation required an the total load on the feeder.

Ques. How is the capacity stated?

Ans. In percentage of the full load of the feeder.

For instance, on a 100 kilowatt circuit, a 10 kw. regulator will giv 10 per cent. regulation, and a 5 kw. regulator, 5 per cent. regulation.

Polyphase Induction Regulators.—The polyphase induc tion regulator is similar to the single phase regulator excep that both the primary and secondary elements are wound with as many sets of coil as there are phases in the circuit.

In construction these windings are distributed throughout the complete circumference of the stationary and moving elements and closely resemble the windings of an induction motor.

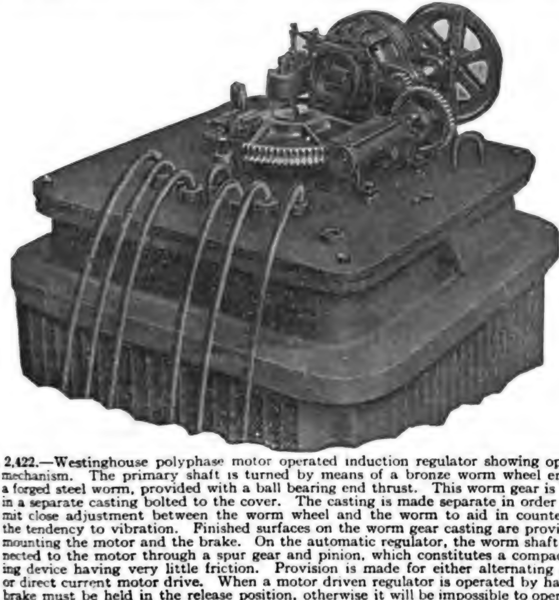


FIG. 2,422.—Westinghouse polyphase motor operated induction regulator showing operating mechanism. The primary shaft is turned by means of a bronze worm wheel engaging a forged steel worm, provided with a ball bearing end thrust. This worm gear is housed in a separate casting bolted to the cover. The casting is made separate in order to permit close adjustment between the worm wheel and the worm to aid in counteracting the tendency to vibration. Finished surfaces on the worm gear casting are provided for mounting the motor and the brake. On the automatic regulator, the worm shaft is connected to the motor through a spur gear and pinion, which constitutes a compact driving device having very little friction. Provision is made for either alternating current or direct current motor drive. When a motor driven regulator is operated by hand, the brake must be held in the release position, otherwise it will be impossible to operate the regulator. In the hand operated regulator the spur gear is replaced by a hand wheel and the regulator is driven directly from the worm shaft.

Polyphase regulators have but little tendency to vibrate because the field across the air gap is the resultant of two or more single phase fields and is of a constant value at all times. This field rotates at a rate depending upon the number of pole and the frequency of the circuit. This produces a mechanical pull of constant value which rotates with the magnetic field varying its position from instant to instant.

It is evident that this pull is of an entirely different character from that produced by the single phase field and that there is no tendency to set up the vibration that the mechanical pull of the single phase regulator tends to establish.

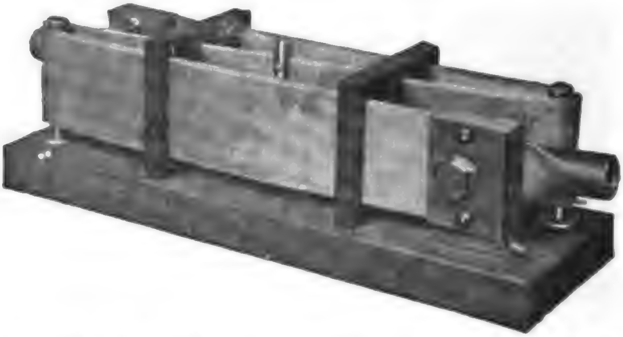


FIG. 2,423.—General Electric **adjustable compensation shunt. It is used** as the compensating shunt for direct current voltage regulators. **In operation,** the shunt may be adjusted so as to compensate for any desired line drop up to 15 per cent. It is preferably placed in the principal lighting feeder but may be connected to the bus bars so that it will take the total current. The latter method is sometimes undesirable, as large fluctuating power loads on separate feeders might disturb the regulation of the lighting feeders. **Adjustment is made** *by sliding the movable contact* shown at the center of the shunt. This contact may be clamped at any desired point and it determines the pressure across the compensating winding of the regulator's control magnet. Where pressure wires are run back to the central station from the center of distribution, they may be connected directly to the pressure winding of the main control magnet, and it is unnecessary to use the compensating shunt.

There is, however, considerable torque developed, and the device for revolving the moving element must be liberally designed so as to withstand the excess torque caused by temporary overloads or short circuits.

Ques. In what respects do polyphase induction regulators differ in principle from single phase regulators?

Ans. The induced voltage in the secondary has a constant alue, and the regulation is effected by varying the phase relaion between the line voltage and the regulator voltage.

Ques. How is the primary wound?

Ans. It is wound with as many separate windings as there re phases in the circuit, and these primary or shunt windings re connected to the corresponding phases of the feeder.

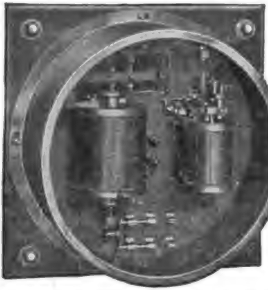


Fig. 2,424.—General Electric **direct current** (form S) **voltage regulator. It consists of** *a main control magnet, relay, condenser and reversing switch,* as shown in the diagram fig. 2,428. This regulator cannot be used for compensation of line drop as the current coil is omitted; it is not a switchboard instrument, but is designed for inexpensive installations such as for regulating the voltage of motor generator sets when the current is taken from a trolley line or some other fluctuating source. **The regulating outfit comprises,** besides the regulator, one or more condenser sections according to field discharge, set of iron brackets when regulator cannot be mounted on front of switchboard, one compensating shunt, when it is desired to compensate for line drop. Field rheostats having sufficient resistance to reduce the voltage the proper amount must be used with voltage regulator installations. To prevent undue decay at the relay contacts, allow one section for each 15 kw. capacity of dynamo with laminated poles, and one for each 22 kw. capacity with solid steel poles.

Ques. What kind of magnetizing flux is produced by the primary windings?

Ans. A practically constant flux which varies in direction

Ques. How is the secondary wound?

Ans. There is a separate winding for each phase.

Ques. Why is the voltage induced in the secondary constant?

Ans. Because of the constant magnetizing flux.

Ques. How is the line voltage varied by a polyphase regulator?

Ans. When the regulator is in the position of maximum boost, the line AB, fig. 2,425 represents the normal busbar voltage, BC the regulator voltage, and AC the resultant feeder voltage. When the regulator voltage is displaced 180 degrees from this position, the regulator is in the position to deliver minimum voltage to the feeder, the regulator voltage being then represented by BD, and the resultant feeder voltage by AD. When the regulator voltage is displaced angularly in the direction BF, so that the resultant feeder voltage AF becomes equal to the normal busbar voltage AB, the regulator is in the neutral position. Intermediate resultant voltages for compensating the voltage variations in the feeders may be obtained by rotating the moving element or primary in either direction from the neutral position. For example, by rotating the primary through the angle FBE, the resultant voltage may be made equal to AE or AJ, thereby increasing the feeder voltage by an amount BJ; or by rotating it in the opposite direction through the angle FBG, the feeder voltage may be reduced by an amount BH.

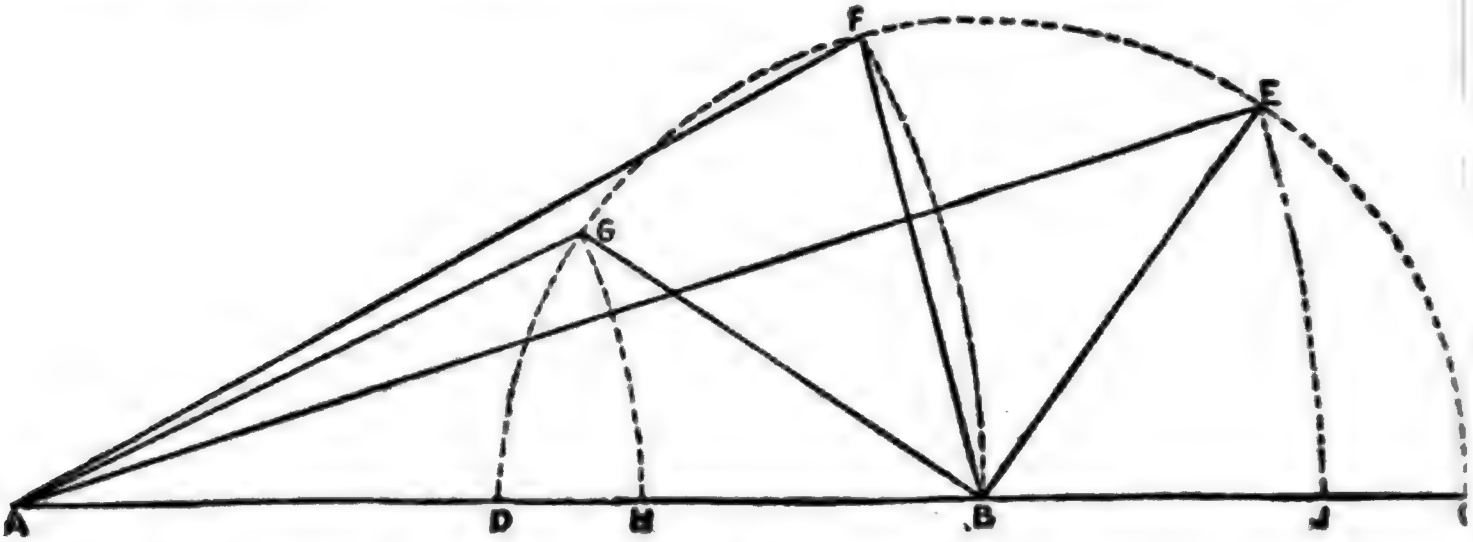


FIG. 2,425.—Diagram illustrating operation of polyphase induction regulator.

Ques. How are induction regulators operated?

Ans. By hand or automatically.

Ques. How is automatic operation secured?

Ans. By means of a small motor, controlled by voltage regulating relays.

Ques. How is the control apparatus arranged?

Ans. Two relays are employed with each regulator, a primary relay connected to the feeder circuit and operating under changes of voltage therein, and a secondary relay connected between the primary relay and the motor, and operated by the contacts

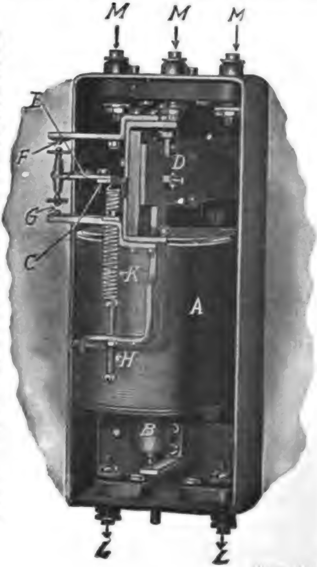


FIG. 2,426.—Westinghouse voltage regulating primary relay; view of mechanism with case removed. This relay is practically a voltmeter arranged for making and breaking contacts with fluctuations of voltage. As shown in the figure, it consists essentially of a solenoid and a balance beam carrying two movable contact points on one end and attached to the solenoid core at the other. The oscillation of the core causes the contact carrying end of the beam to move between two stationary contact points connected to the auxiliary or secondary relay circuit. The stationary contact points are fitted with adjusting screws for either increasing or decreasing the distance between them, to the amount of change in the voltage required for making or breaking contact; in other words, for varying the sensitiveness of the relay. Means for varying the normal voltage which it is desired to maintain are provided in the spring attached to the balance beam and controlled by the micrometer adjusting screw. Increasing the tension of the spring results in lowering the normal voltage position. The relay is wound for a normal voltage of 110 volts, and has a range of adjustment from 90 to 130 volts. The total energy required for its operation is about 50 watts at normal voltage. Voltage transformers having at least 50 watts capacity are, therefore, required. The parts are: A, solenoid; B, solenoid core; C, end of balance beam; D, pivots, bearings; E, movable contact arm; F, upper stationary contact point; G, lower stationary contact point; H, adjusting screw; K, adjusting spring; L, feeder binding posts; M, auxiliary circuit and secondary relay binding posts.

of the former, for starting, stopping and reversing the motor i accordance with changes in the feeder voltage, thereby causin the regulator to maintain that voltage at its predetermine normal value.

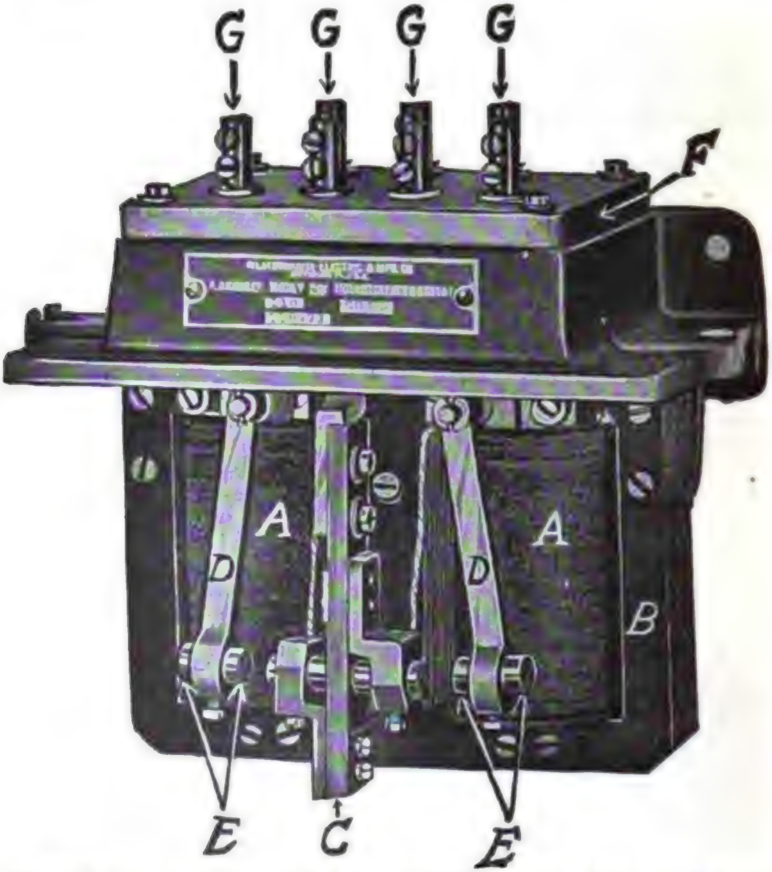


FIG. 2,427.—Westinghouse voltage regulating **secondary** relay; view showing relay remov from oil tank. The secondary relay is practically a motor starting switch of the dou pole double throw type, electrically operated through the contacts of the primary rel It is provided with contact points of one-half inch rod. The relay is suitably connect for starting, stopping and reversing the motor and for properly operating the mot brake. The parts are: A, solenoid; B, laminated field; C, movable contact arm; stationary contact arms; E, removable brass contact points; F, terminal block; G, te minals.

Ques. Why are two relays used?

Ans. For the reason that a primary relay, of sufficien accuracy and freedom from errors due to temperature an frequency variations, could not be made sufficiently powerful to carry the relatively large current required for operating the motor.

Ques. What names are given to the relays?

Ans. Primary and secondary.

Ques. What difficulties were encountered in the operation of relays?

Ans. Vibration or chattering at the contacts of both relays and tendency of the movable contact arm of the primary relay to hug closer to one of the stationary contact points than to the other, thereby operating too often.

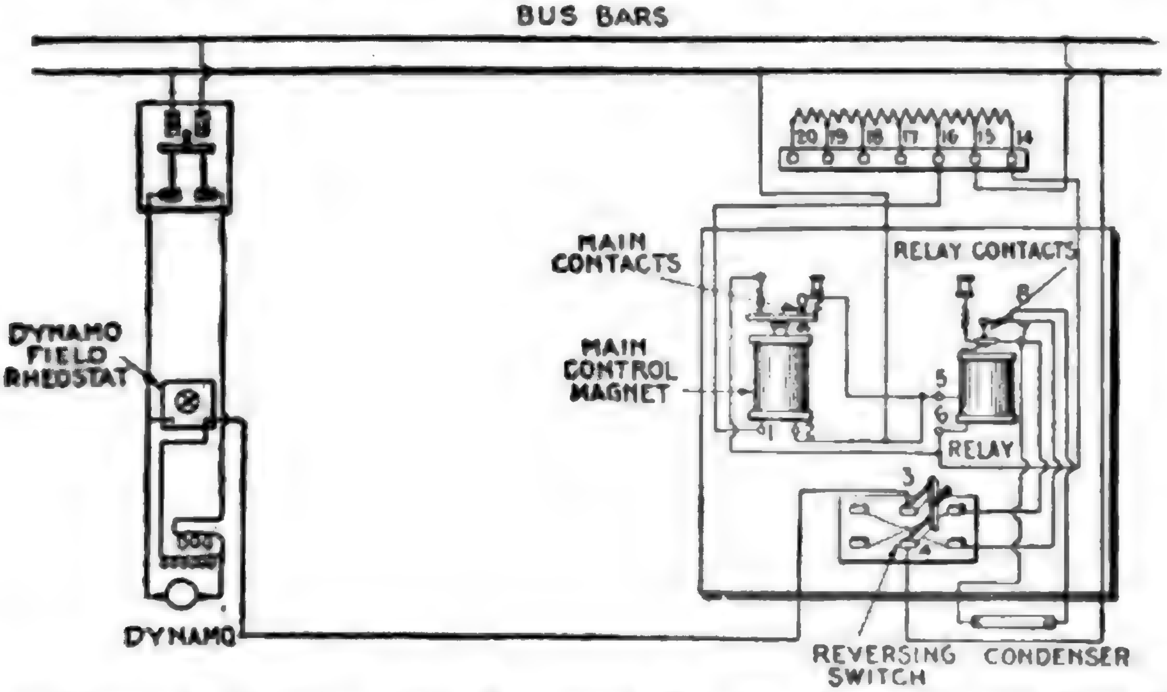

BUS BARS
DYNAMO FIELD RHEOSTAT
DYNAMO
MAIN CONTACTS
MAIN CONTROL MAGNET
RELAY CONTACTS
RELAY
REVERSING SWITCH
CONDENSER
20
19
18
17
16
15
14
5
6
3

FIG. 2,428.—Diagram of connections of General Electric **direct current** (form S) **voltage regulator,** for 125, 250, and 550 volts. **The range of voltage** is given in the following table:

Regulator	Range of voltage				
	16	17	18	19	20
125.	105	110	115	120	125
250.	210	220	230	240	250
550.	550				

Ques. What causes vibration or chattering at the contacts?

Ans. This is due to the voltage frequently approximating the value required for closing a contact, thereby causing the contact points to barely touch and make several poor contacts in succession.

Ques. What objectionable action is produced by vibration at the contacts?

Ans. Arcing, burning and pitting of the contacts, even when alloys of the rarer metals are used, such as those of the platinum group, having extreme hardness and high melting points.

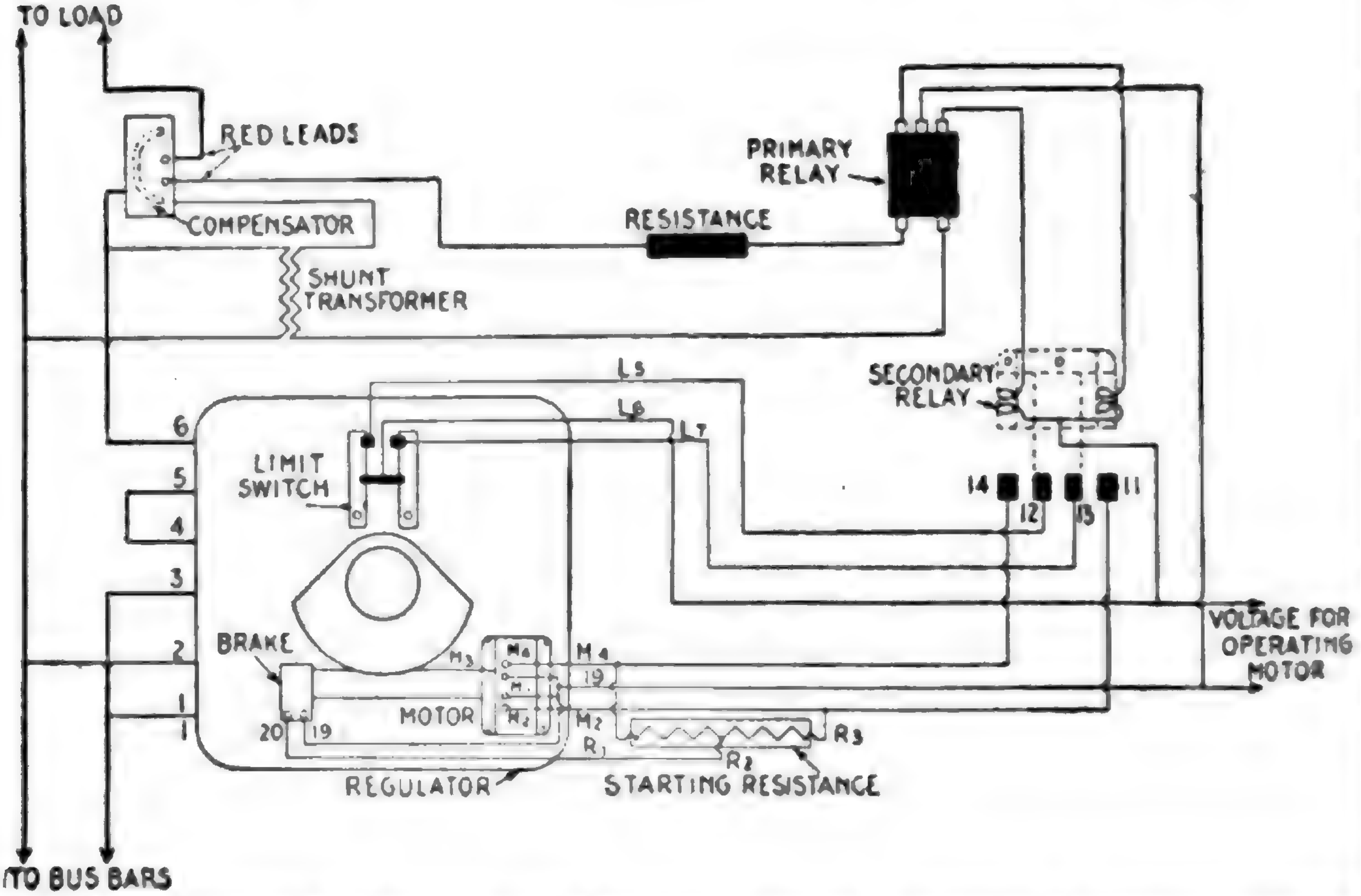

TO LOAD
RED LEADS
COMPENSATOR
SHUNT TRANSFORMER
RESISTANCE
PRIMARY RELAY
SECONDARY RELAY
L5
L6
L7
LIMIT SWITCH
6
5
4
3
2
1
1
BRAKE
H_3
H_4
H_2
19
20
19
MOTOR
R_1
R_2
R_3
REGULATOR
STARTING RESISTANCE
14
12
13
11
VOLTAGE FOR OPERATING MOTOR
TO BUS BARS

FIG. 2,429.—Diagram of connections of automatic induction regulator and auxiliary apparatus on single phase circuit.

Ques. What effect is produced by poor contact of the primary relay?

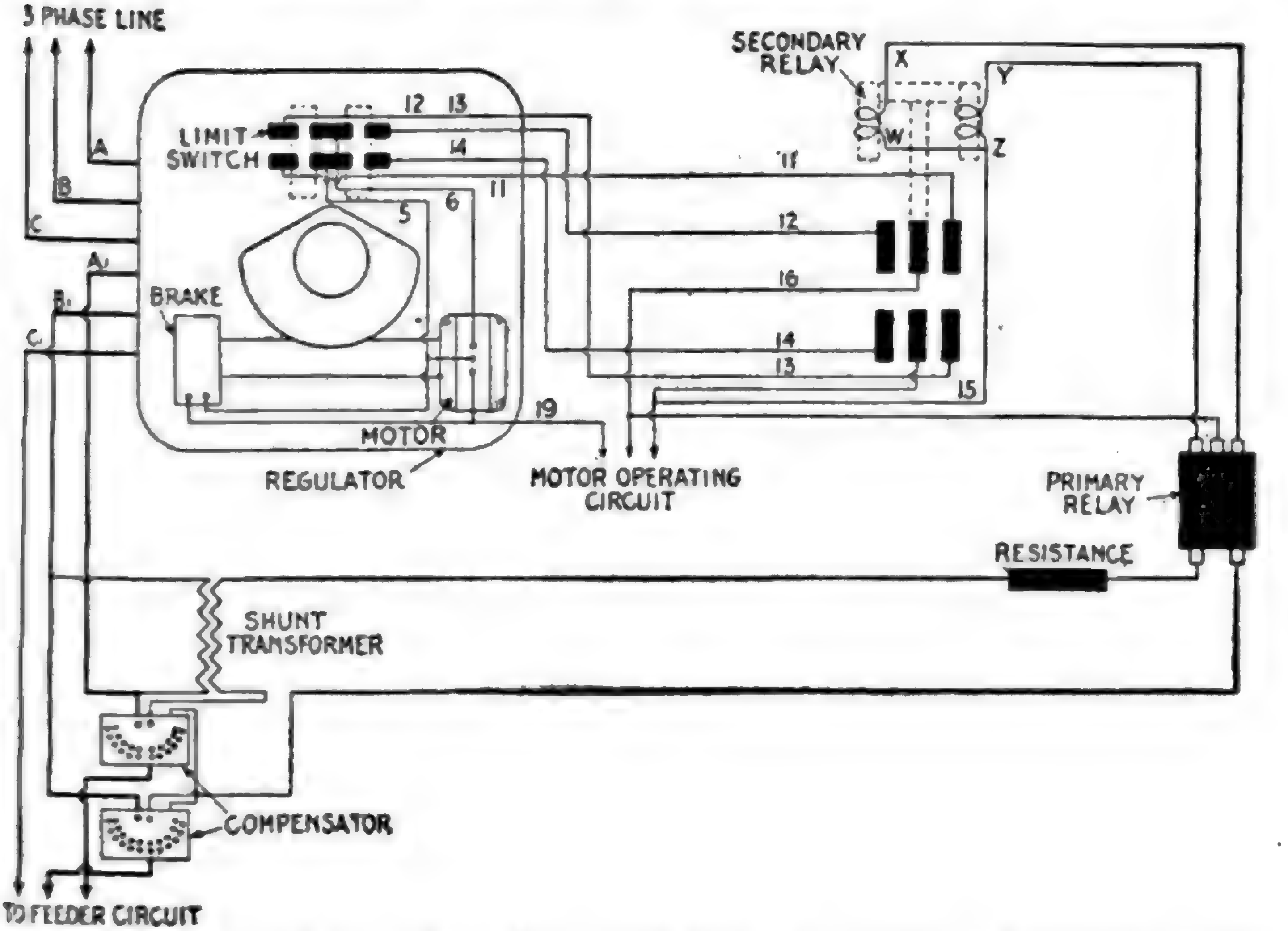
Ans. It causes chattering in the secondary relay; which burns out and wears away its contact points, increasing the heating of the motor, creating objectionable noise and entailing wear and tear on the whole outfit.

Ques. Why does the movable contact arm of the primary relay tend to remain nearer one of the stationary contact points than the other?

Ans. This is due to the tendency of the relay to open the contact whenever the voltage equals that at which the contact closes.

Ques. What provision is made in the primary relay to prevent vibration or chattering?

Ans. Two auxiliary windings are provided: one in series vith each of the stationary contact points and so arranged as o assist in making the contact by increasing the pressure on he contact points at the instant of closure.


3 PHASE LINE
SECONDARY RELAY
X
Y
W
Z
LIMIT SWITCH
12
13
14
11
A
B
C
5
6
11
12
16
A1
B1
C1
BRAKE
14
13
15
19
MOTOR
REGULATOR
MOTOR OPERATING CIRCUIT
PRIMARY RELAY
RESISTANCE
SHUNT TRANSFORMER
COMPENSATOR
TO FEEDER CIRCUIT

ɪc. 2,430.—Diagram of connections of automatic induction regulator and accessory apparatus on three phase feeder circuit.

The best effect of the compounding action of the auxiliary coils is obtainable when arranged for ½ per cent. of the torque of the main coi

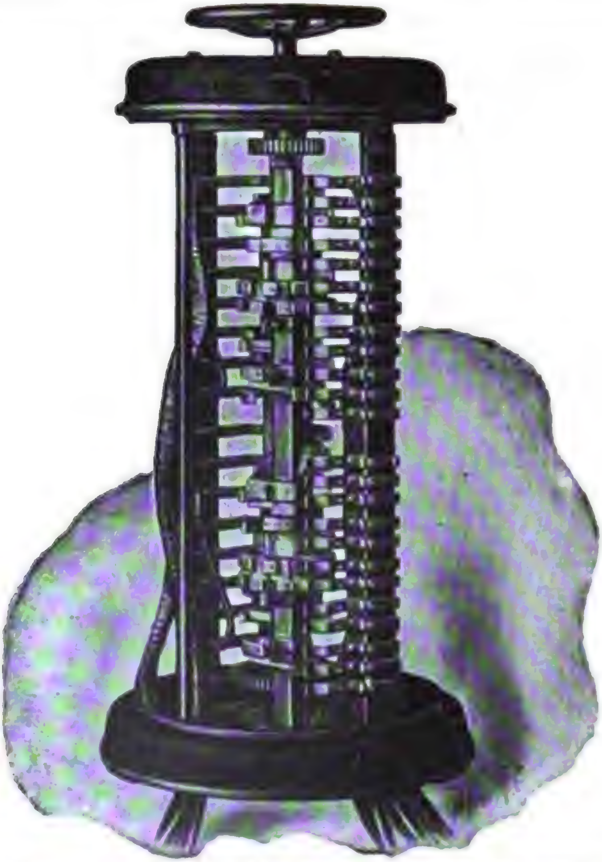


FIG. 2,431.—Westinghouse drum type variable transformer voltage regulator. It consists of a drum and finger type switch. A preventive resistance is used between the different contacts, making it unnecessary to open the circuit when moving from one tap of the regulating transformer to the next tap. A spring actuated, quick moving, central stopping mechanism is used to prevent burning the resistances. The regulator is arranged to give 40 points of regulation. In many cases this large number of points is not absolutely necessary, but it is desirable to use them because the voltage per step is thus reduced to a small value, and a corresponding increase in the life of the contacts results because of the reduced sparking at the lower voltage. **Two drums** are employed. The **first drum** has ten contacts and a corresponding number of fingers, the latter being mounted upon an insulated bar. These fingers are connected to the floating coils of the regulating transformer, and as the drum is rotated, the finger connected to the line is brought into contact successively with each of the ten taps. The **second drum** is of similar construction and consists of a changing and reversing switch. It connects the two floating coils to the various taps on the main secondary coil of the regulating transformer at the proper time, and also reverses the transformer so that the total winding can be used for either raising or lowering the voltage. All the points of regulation are obtained by a continuous motion of the handle, the various connections produced in the manner are shown in the diagram, fig. 2,433. The top and base of the regulator are made of cast iron and the top is supported by steel bars, two of which are insulated, and used to support the metallic bases finger to which the cable leads are attached. The drums consist of metal castings mounted upon insulated shafts. The first drum, which is the only one upon which arcing can take place, is provided with removable copper contact tips. The main castings are made of aluminum to secure low inertia of the drum. A sheet iron cover is used to enclose the regulator, and the leads are brought out through the bottom of the controller.

A non-inductive resistance placed in parallel with each coil of the secondary relay, takes current approximately in phase with the current in the main coil of the primary relay, and of proper strength to make the number of ampere turns in the auxiliary coil three-fourths per cent. of the number in the main coil. The resistances have the additional effect of absorbing the "discharge" from the main coils of the secondary relay when the contacts are broken, thereby obviating sparking at the primary contact points.

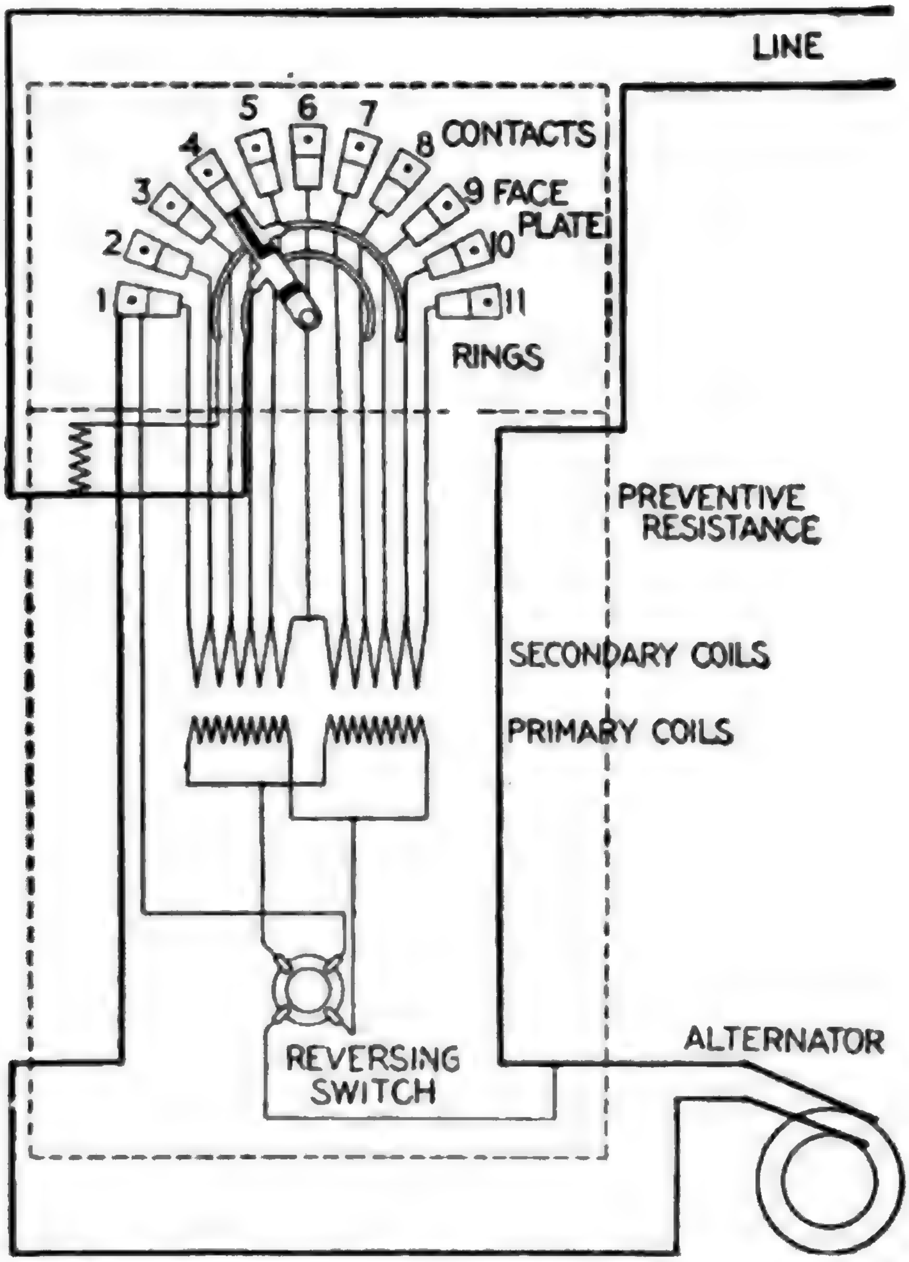

LINE
1
2
3
4
5
6
7
8
9
10
11
CONTACTS
FACE PLATE
RINGS
PREVENTIVE RESISTANCE
SECONDARY COILS
PRIMARY COILS
REVERSING SWITCH
ALTERNATOR

FIG. 2,432.—Diagram showing connections of the Stillwell regulator.

Variable Ratio Transformer Voltage Regulators.—The principle of operation of this class of regulator is virtually the same as that of the induction type regulator; that is to say, both consist of regulating transformers, but **in the variable ratio method** *the primary or series coil is divided into a number* *of sections which may be successively cut in or out of the circuit to be regulated,* instead of varying the flux through the entire coil, as in the induction type. There are two distinct mechanical forms of variable ratio regulator:

1. Drum type;
2. Dial type.

Drum Type Regulators.—This form of variable ratio transformer consists essentially of a drum and finger type switch similar to a railway controller.

There are many contacts, giving a large number of points of regulation, obtained by the use of changing switches and floating coils.

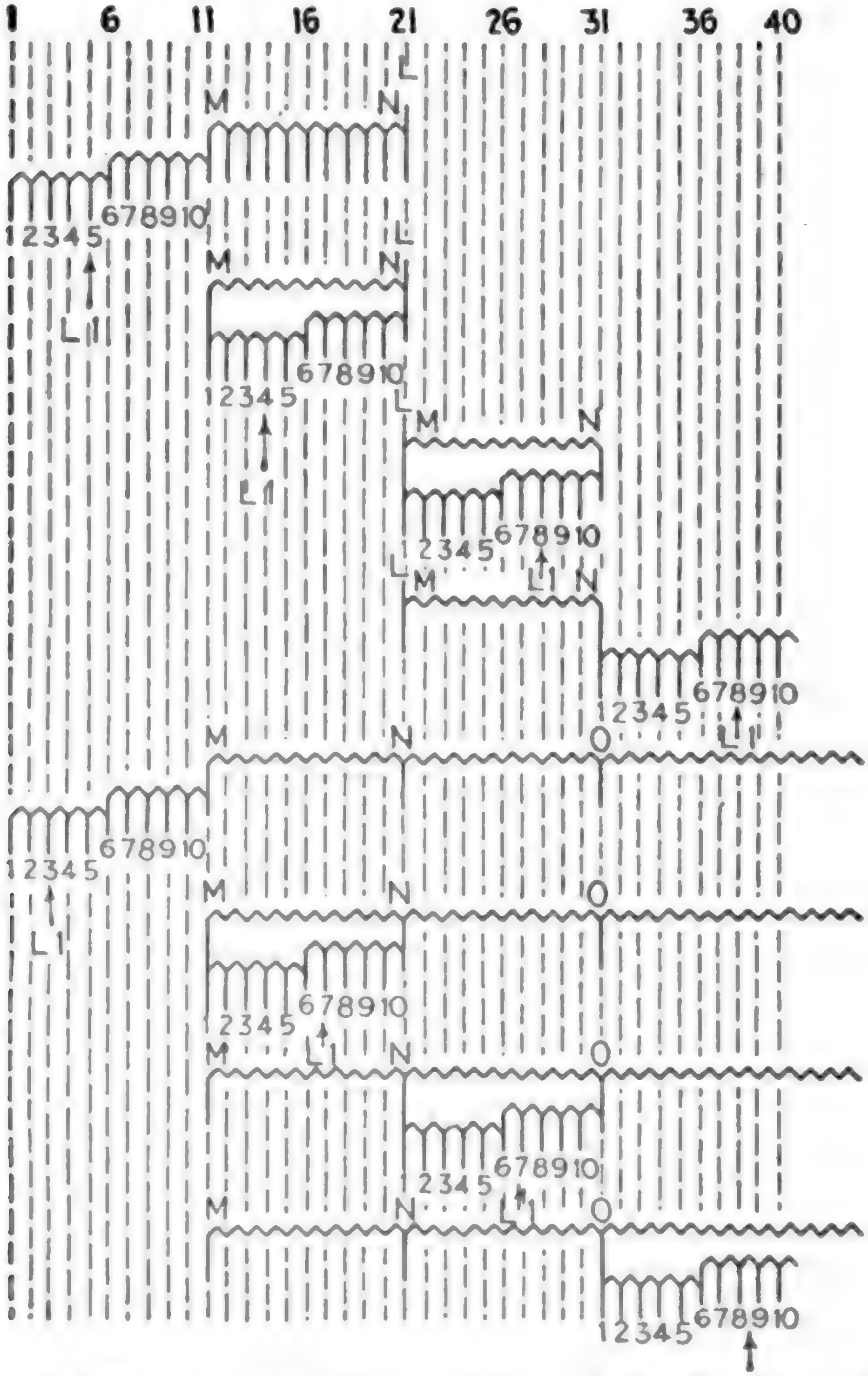


FIG. 2,433.—Diagram showing **position of the floating coil** on different steps of Westinghouse **drum type variable ratio transformer regulator.** *The upper half of the diagram* shows the connections of the various coils for each position of the regulator handle. This arrangement applies to a regulator used in connection with an independent regulating transformer. When regulators are used in connection with large power transformers, the regulating transformer can be omitted and auxiliary coils can be placed on the main transformer to provide the necessary taps for regulating purposes. *The lower half of the diagram* shows the connections used when auxiliary coils are added to a large transformer. **The diagram shows** connections for a **single phase regulator.** Where polyphase regulators are required, the connections consist essentially of two sets of single phase connection, and the controller is extended in length so as to contain double sets of drum and contact.

The floating coil is a part of the secondary winding of the regulating transformer which is insulated from the main portion of the winding, and is sub-divided by taps into a number of equal sections.

The sub-divisions of the main secondary winding are much larger, each one being equivalent to the whole of the floating coil.

Ques. Describe the operation of a drum regulator.

Ans. The floating coil and main windings are first connected in series with each other and with the line to be regulated. The floating coil is then cut out of the circuit step by step. When entirely cut out it is transferred to the next lower tap on the main winding, after which it is again cut out step by step and then transferred again. By continuing this process a large number of steps are provided with but comparatively few actual aps on the transformer.

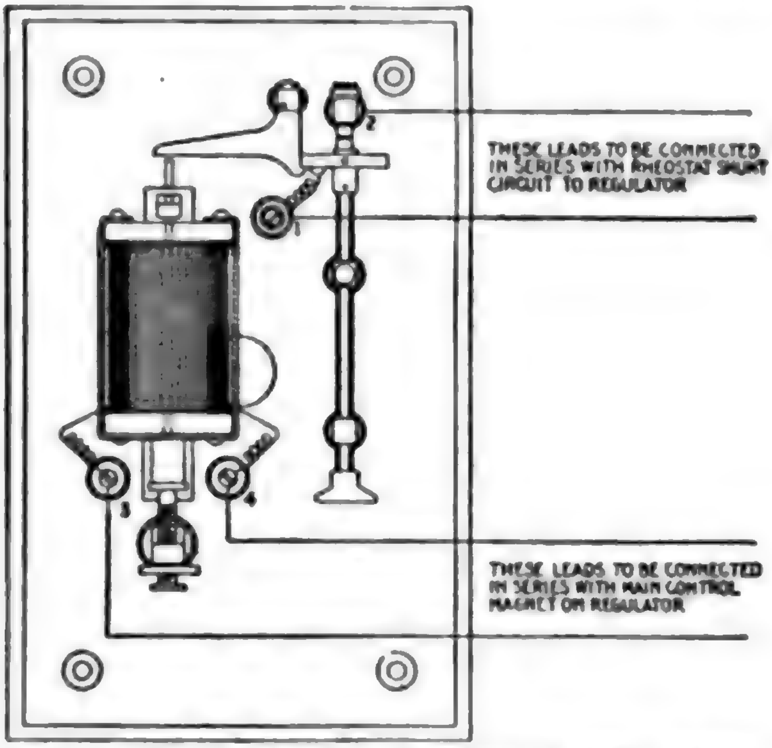

1
2
3
4
THESE LEADS TO BE CONNECTED IN SERIES WITH RHEOSTAT SHUNT CIRCUIT TO REGULATOR
THESE LEADS TO BE CONNECTED IN SERIES WITH MAIN CONTROL MAGNET ON REGULATOR

FIG. 2,434.—Diagram of connections of General Electric **high voltage cut out relay** (form A) for voltage regulators. **Its use** in connection with the regulator protects the system from any sudden rise in voltage due to some accident to the regulator which might cause the relay contacts to stick, thus producing *full field* on the exciter. **In construction,** *the control magnet is connected in series with the alternating current control magnet on the regulator and the contacts are connected in series with the rheostat shunt circuit.* Then, **should the voltage rise beyond a certain value,** predetermined by the setting of the thumb screw supporting the plunger of the control magnet, *the contacts of the relay are tripped open which, by inserting all the resistance in the exciter field, reduces the exciter voltage which in turn reduces the alternating current voltage.* This relay has to be reset by hand.

Ques. How many floating coils are used and why?

Ans. Two floating coils are included in each regulator so that one can be transferred while the other is supplying the current to the line.

Dial Type Regulators.—This form of variable ratio transformer regulator consists of a regulating transformer and a dial type switch as shown in the accompanying illustrations. The regulating transformer is similar to a standard transformer except that the secondary winding is provided with a number of taps leading to the contact of the dial switch as shown in the diagram fig. 2,437.

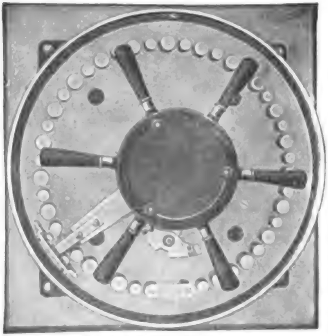


FIG. 2,435.—Dial of Westinghouse dial type variable ratio voltage regulator. The dial consists of a marble slab, upon which the contacts are mounted in a circle as shown. The contact arm is arranged to move from contact to contact. The alternate small contacts are dummies, serving to prevent the contact arm springing down between contacts when moving from one to another. The panel contains a changing switch which makes it possible to double the range of a regulator, since the transformer connections can be changed to both raise and lower to an extent equal to the full range of the transformer. The total range in voltage from a certain per cent. below to a certain per cent. above the line voltage can be obtained in a number of steps equal to twice the number of divisions into which the secondary winding of the transformer is divided.

Ques. What modification is made to adapt dial regulators for heavy current?

Ans. A dial with a series transformer, and a shunt or auto-transformer are employed as shown in fig. 2,436.

Ques. Why is such modification desirable?

Ans. Because, the additional cost of a series transformer is small in comparison with the cost of building a dial with a large current carrying capacity, and the cost of bringing out a number of heavy leads from a small transformer.

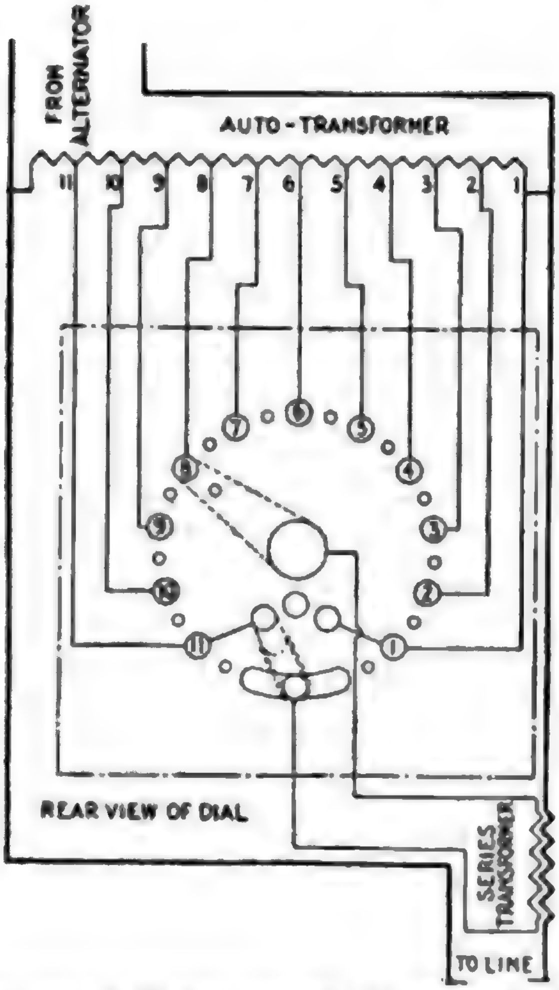


FIG. 2,436.—Diagram of connections for Westinghouse **11 point dial, series transformer and auto-transformer.** The auto-transformer has a number of taps connected across the line, the series transformer is placed in series with one side of the line, and connected to a dial, as shown.

Ques. How are dial regulators modified for high voltage?

Ans. Standard dials may be used with series and shunt transformers similar to the method used for heavy current circuits.

Ques. Describe the connections.

Ans. The primary of the shunt tra[illegible] across the line and the secondary has a [illegible] are connected to contacts on the dial. Th[illegible] transformer is connected in series with [illegible] from the secondary winding are connect[illegible]

The connections are similar to those [illegible] shunt transformers are used instead of auto[illegible]

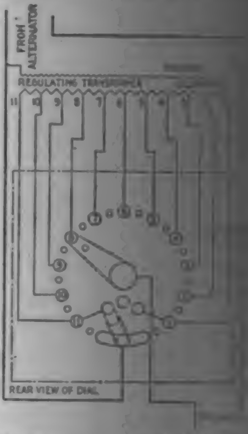


FIG. 2,437.—Diagram of connections for Westinghouse dial [illegible] former. **In construction** the secondary windi[illegible] 14, or 20 parts giving 11, 15, or 21 taps which are [illegible] ing and connected to the various points of the dial. [illegible] for an 11 point dial and regulating transformer. Sin[illegible] between adjacent contacts, *the contact arm must* [illegible] *it is moving until after it has left the contact* [illegible] is undesirable to open the circuit each time in m[illegible] These conflicting requirements are met by the use [illegible] the contact arm so that a very close adjustment [illegible] the contacts are not short circuited but always [illegible] eighth inch in the circuit during the time of changing [illegible] air gaps form a "preventive resistance." A quick [illegible] erate the movement from one contact to the next, [illegible] sary to avoid undue arcing. The capacity of the regulat[illegible] being arranged to give a maximum increase in voltage of [illegible] sure between contacts is 25 volts.

Ques. Describe the connections.

Ans. The primary of the shunt transformer is connected across the line and the secondary has a number of taps which are connected to contacts on the dial. The primary of the series transformer is connected in series with the line and two leads from the secondary winding are connected to the dial.

The connections are similar to those shown in fig. 2,437, except that shunt transformers are used instead of auto-transformers.

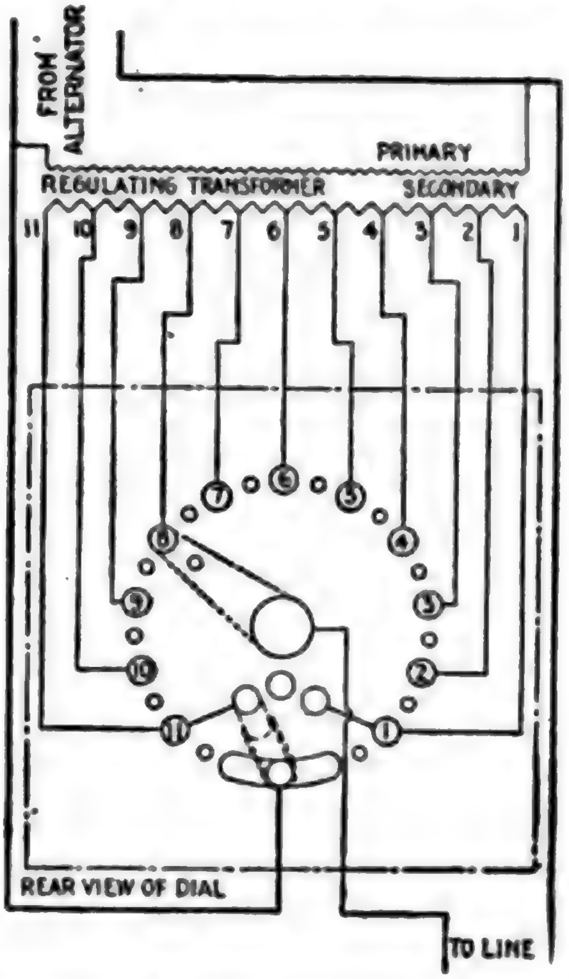


Fig. 2,437.—Diagram of connections for Westinghouse **dial type variable ratio voltage transformer.** **In construction** the secondary winding of the transformer is divided into 10, 14, or 20 parts giving 11, 15, or 21 taps which are brought out from the secondary winding and connected to the various points of the dial. The diagram shows connections for an 11 point dial and regulating transformer. **Since there is a difference of voltage** between adjacent contacts, *the contact arm must not touch the contact toward which it is moving until after it has left the contact upon which it was resting.* Moreover, it is undesirable to open the circuit each time in moving from one contact to the next. These conflicting requirements are met by the use of arcing tips which are placed on the contact arm so that a very close adjustment can be obtained, and so arranged that the contacts are not short circuited but always have a gap of from one-sixteenth to one-eighth inch in the circuit during the time of changing from one contact to the next. The air gaps form a "preventive resistance." **A quick moving mechanism** is used to accelerate the movement from one contact to the next, a very quick movement being necessary to avoid undue arcing. **The capacity of the regulator** is 200 amperes at 2,200 volts, being arranged to give a maximum increase in voltage of 400 volts. The maximum pressure between contacts is 25 volts.

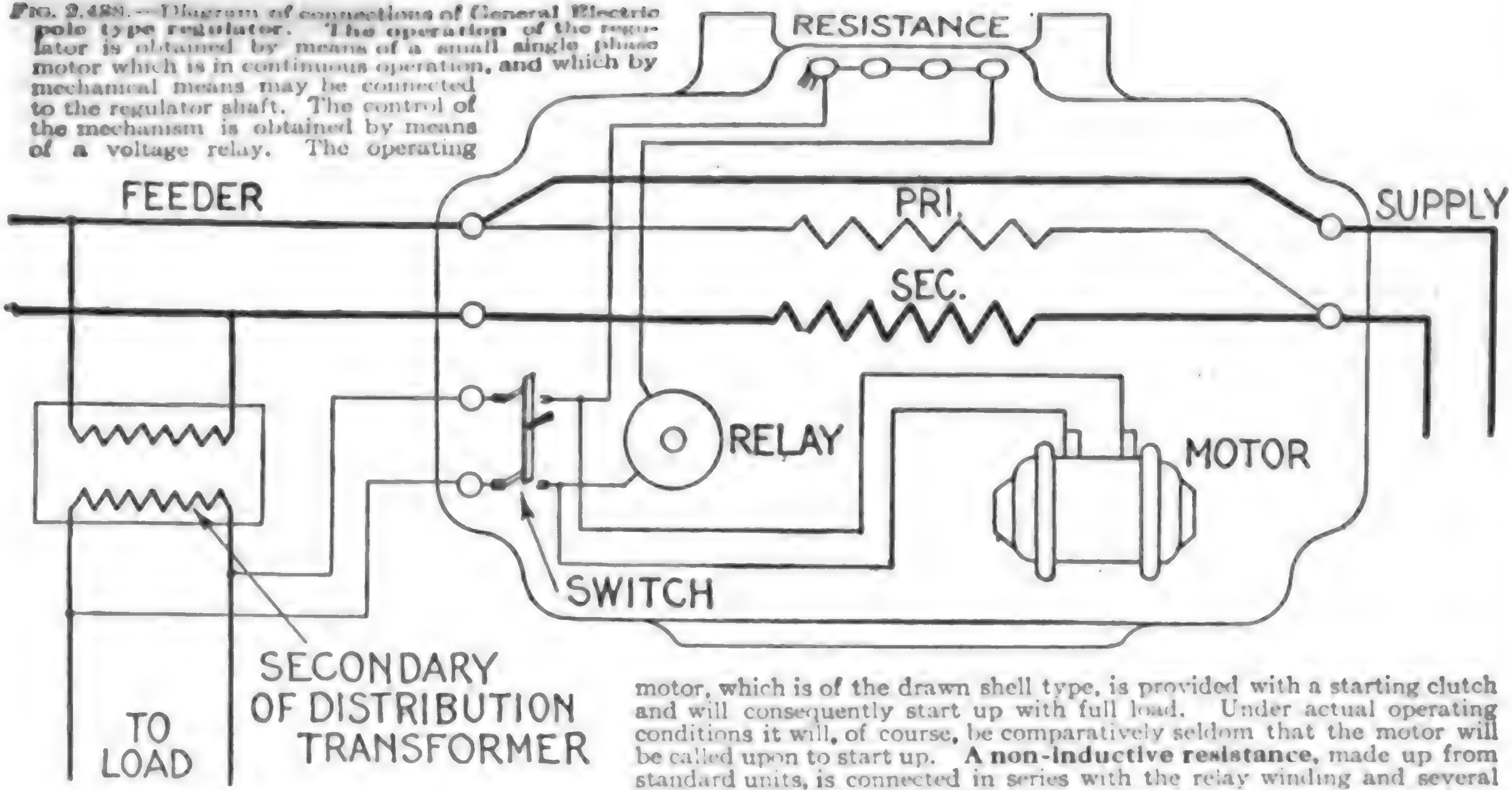
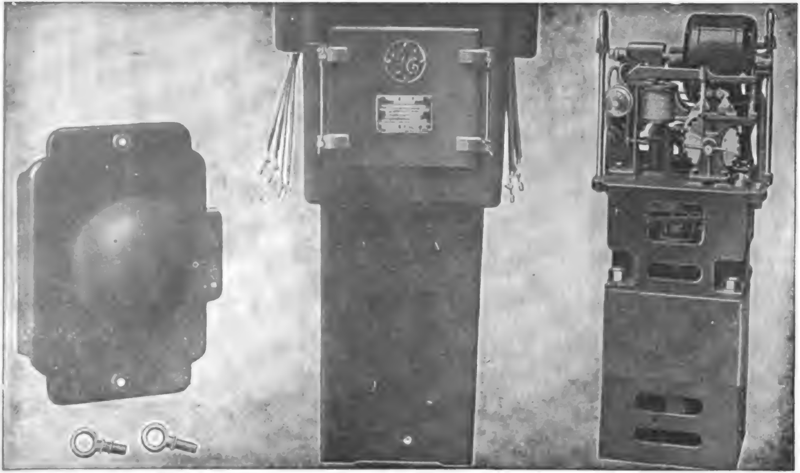
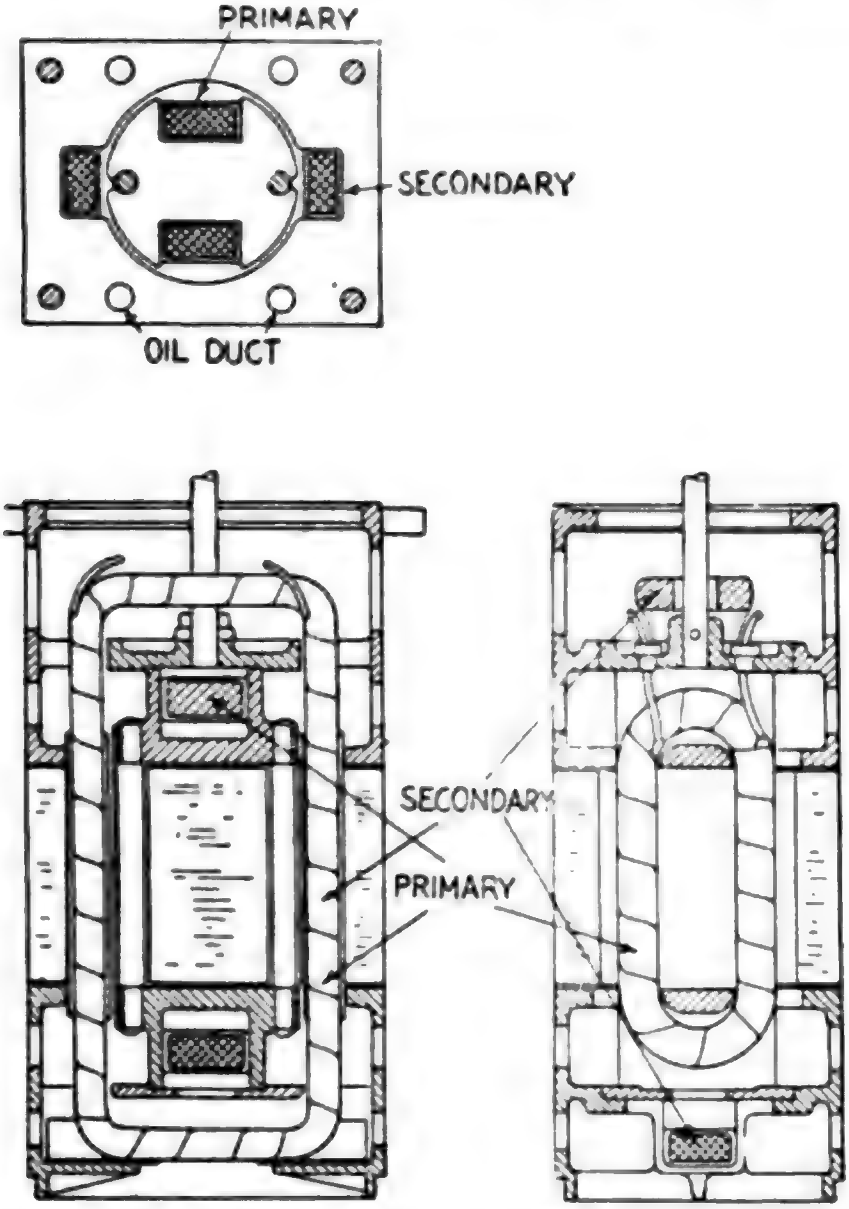


FIG. 2,488.—Diagram of connections of General Electric pole type regulator. The operation of the regulator is obtained by means of a small single phase motor which is in continuous operation, and which by mechanical means may be connected to the regulator shaft. The control of the mechanism is obtained by means of a voltage relay. The operating motor, which is of the drawn shell type, is provided with a starting clutch and will consequently start up with full load. Under actual operating conditions it will, of course, be comparatively seldom that the motor will be called upon to start up. **A non-inductive resistance,** made up from standard units, is connected in series with the relay winding and several taps are provided, so that the relay can be adjusted for any voltage from 10 per cent. below normal. In order to readily dissipate the heat developed in the resistance, it has been mounted in a pocket on the back of the tank, openings being provided for natural air ventilation. **The relay plunger** is hinged to one end of a balance arm, which arm is provided with two trip pins to control the mechanism. **An adjustable helical spring** is attached to the other end of the arm to assist the magnetic pull of the coil in balancing the plunger and also for adjustment. The relay is not provided with series winding for line drop compensation, but it may be used with a standard line drop compensator, which then has to be installed outside of the regulator. The voltage relay must be connected to the feeder side of the regulator, the necessary low voltage to be obtained from a distributing transformer, or if this should not be available in the immediate vicinity, a 200 watt step down transformer will be satisfactory. **The motor is designed to operate** in parallel with the relay, the normal connections being as shown. The speed of the motor and the ratio of the gearing is such that it requires about 90 seconds to operate the regulator from limit to limit, but, as this regulator is not intended to take care of sudden voltage fluctuations, the comparatively long time of operation will not be objectionable.



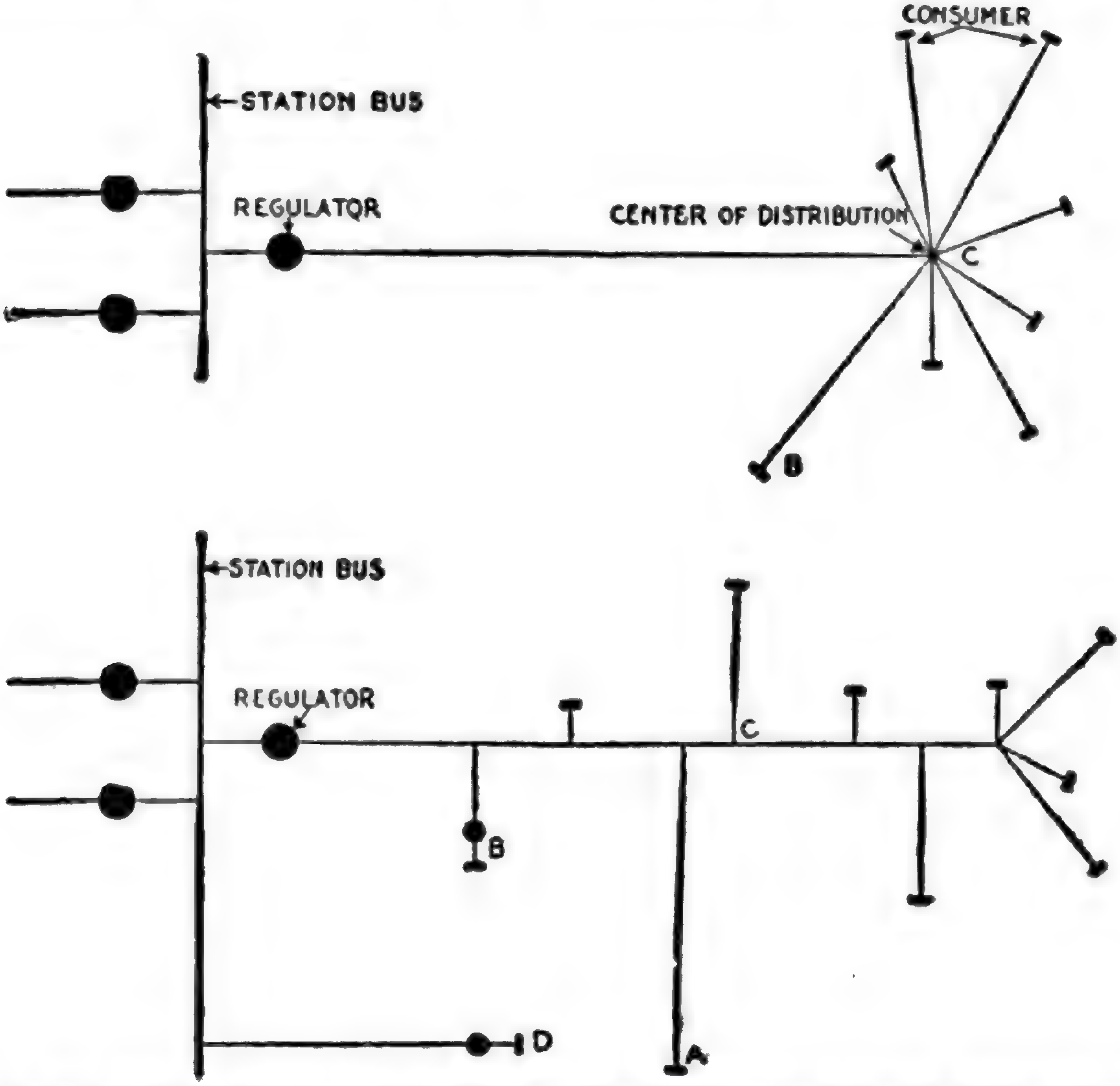
FIGS. 2,439 to 2,443.—General Electric **pole type regulator** removed from tank. **It consists essentially** *of a primary and secondary coil, operating motor, and voltage relay mechanism.* The regulator and mechanism is suspended in a cast iron tank, the lower part, containing the regulator core and coils, being filled with oil. The leads for the regulator are brought out at the upper part of the tank. The outgoing leads are compressed into bushings and connected to the leads of the regulator by means of terminals, the arrangements being such that the regulator with mechanism can be removed from the tank without difficulty. Besides the cover, the tank is also provided with a hinged door on the front side so as to give access to the mechanism. The door is provided with a gasket and the construction is practically rain and dust proof. However as there is always danger of the door not being clamped down perfectly, thus making it possible for water to enter the tank, a pocket has been provided inside the tank and underneath the door to collect the water. Capacity up to 2.3 kw., to control 2,300 volts, 60 cycle, 10 ampere feeders, and for a voltage range of 10 per cent. above or below normal, the operating motor and relay being designed for 110 or 220 volts. No provision is made for line drop compensation, although this can be obtained by installing a current transformer and a line drop compensator externally to the regulator.

It will be seen that the circuit comprising the dial, the secondary of the shunt, transformer and the secondary of the series transformer form a circuit which is not electrically connected to the main circuit. It can therefore be grounded without disturbing the main circuit as a safeguard to render it impossible for the pressure of the dial to be higher above the ground than the secondary voltage of the shunt transformer.



FIGS. 2,444 to 2,446.—Sectional views of General Electric pole type regulator winding and core. The secondary core has only two slots containing a single coil, while the rotor or primary core has four slots. Two of these slots are occupied by a single primary coil, and the two circular slots in quadrature thereto contain the compensating or short circuit winding. This winding also serves to hold the primary punchings together, and it consists of two copper rods riveted to the two cast brass flanges. The secondary coil is form wound, while the primary coil is wound directly on the core. The rotor flanges, both top and bottom, are provided with discs which are turned in alignment with the punchings, and these discs bear against the top and bottom flanges between which the secondary punchings are clamped. These secondary flanges are also turned in alignment with the secondary punchings, so that an even air gap between the primary and the secondary is assured. The secondary coil is wound with an opening in the upper horizontal part which affords passage for the operating shaft of the rotor. A bearing for this shaft is provided in the table which supports the mechanism and from which the regulator is suspended. Flexible leads are brought out from the rotor and twisted around the shaft as in standard regulator practice. The regulator being two pole, the rotor is turned through an angle of 180 deg. to obtain the full range of the regulator.

Small Feeder Voltage Regulators.—In some generating stations the voltage is maintained constant at the busbars and the line drop compensated by automatically operated regulators connected in the main feeders. It is possible in this way to obtain constant voltage at all loads at the various distribution centers, that is, at those points on the feeders where the lines of the majority of consumers are connected as shown in fig. 2,447.



Figs. 2,447 and 2,448.—Systems of distribution illustrating use of **small feeder or pole type voltage regulators.**

It is evident, however, that, while the voltage at the center of distribution can be maintained constant, no account can be taken of the drop in the lines between this center and the consumers. This drop is generally negligible, except in some particularly long lines, as, for example, consumer *B* in fig. 2,447.

In order to obtain perfect regulation at B, it would be necessary to install a separate regulator in that line, this regulator to be installed either at the center C or preferably at B.

In a great many cases the power distribution is not as ideal as indicated in fig. 2,447, but rather as shown in fig. 2,448, that is, the consumers are connected all along the feeder. In this case there is no definite center of distribution, and the automatic regulator installed in the station can be adjusted to give only approximately constant voltage at an imaginary center of distribution C; that is, the voltage cannot be held constant at any definite point during changes of load distribution.

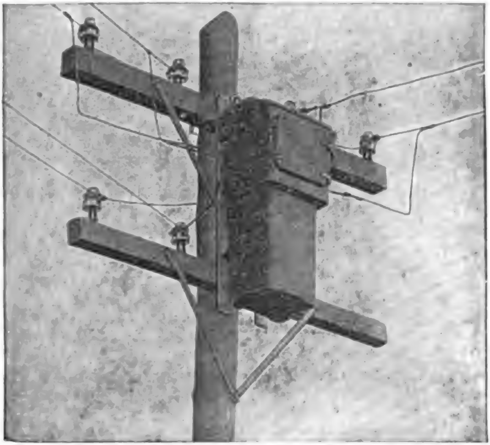


FIG. 2,449.—General Electric pole type regulator in service; its construction is shown in fig. 2,450.

The majority of the consumers may, however, obtain sufficiently good voltage while a few may have reason for criticism. To overcome this difficulty it is necessary either to increase the copper in the feeder or else to install small automatic regulators.

There are also cases where a small amount of power is transmitted a long distance through a feeder direct from the station.

The amount of copper required to reduce the line drop is usually too great to be considered and the cost of the ordinary automatic regulator is also comparatively high. In such cases small pole type regulators as shown in fig. 2,449 are desirable.

Ques. Describe the operation of the regulator mechanism shown in fig. 2,450.

Ans. Assuming the voltage to be normal, the balance arm of the relay will be held horizontal, the trips F will not engage

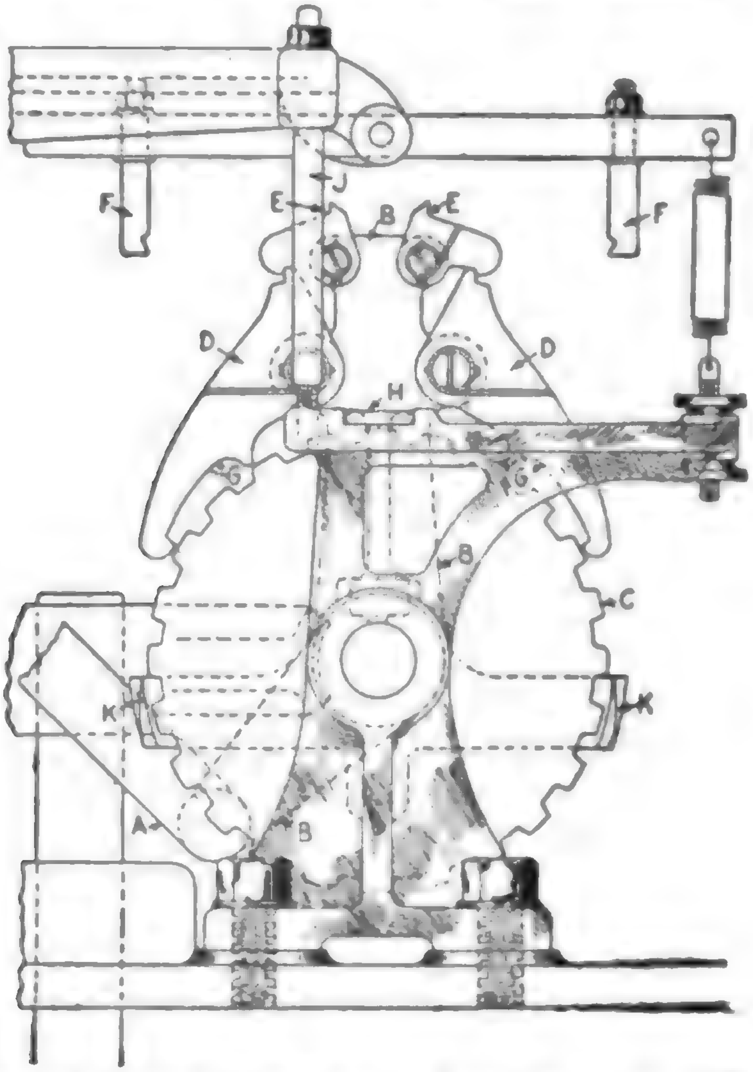


FIG. 2,450.—Mechanism of General Electric pole type regulator. The operating motor (described in fig. 2,438) is direct connected to a worm and gear, the shaft of which is provided with a bell crank. A rod A, connects the crank with the rocker arm B, which th may be caused to oscillate over a ratchet wheel C. The rocker arm is provided wi two pawls D, which can engage with the teeth of the ratchet wheel, so that this whe can be rotated one way or the other. The ratchet wheel is mounted on the same shaf as a worm, which engages with the gear segment carried by the regulator shaft, so tha the movement of the ratchet wheel is directly transmitted to the regulator. Besides th two large pawls D, the rocker arm also carries two smaller ones E, called the trigger These triggers usually hold the pawls locked in such positions as not to engage with th ratchet wheel, but the pawls will be released when the triggers strike the trips F of th relay arm. A limiting device for the movement of the ratchet wheel and the regulato segment is provided, as shown. This device consists of two cams K, mounted on a common arm, which can turn on the shaft of the ratchet wheel. Normally these cams ar not within reach of the pawls, but through a lever arrangement, controlled by the regulator segment, the arm holding the cams may be rotated so that, if the trigger has bee raised, so as to release the pawl, the tip of the pawl will bear on the cam of the limitin device, and before the pawl can engage with the ratchet wheel it has already been lock by its trigger. A further movement of the ratchet wheel in that particular direction therefore impossible, while it is free to be moved the other way. A positive stop for th gear segment is also provided. The motor is provided with oil ring bearings, and th gear for the motor worm runs in oil, the supporting casting forming a well therefor.

with the triggers E, and no movement is therefore transmitted to the ratchet wheel C. If the voltage drop below normal, the left hand trip will descend until it finally gets in the way of the left hand trigger just before it reaches the limit of its counter-clockwise travel. This trigger will therefore release the left pawl D, which will engage with the ratchet wheel and will consequently turn it clockwise until the rocker arm reaches its right hand limit. Before the rocker arm reaches the left hand imit, the released pawl must be locked by its trigger, so that f the voltage has reached its normal value, further movement of the ratchet wheel will not take place, whereas if the voltage be still too low, the trigger will again release the pawl by striking he trip of the relay.

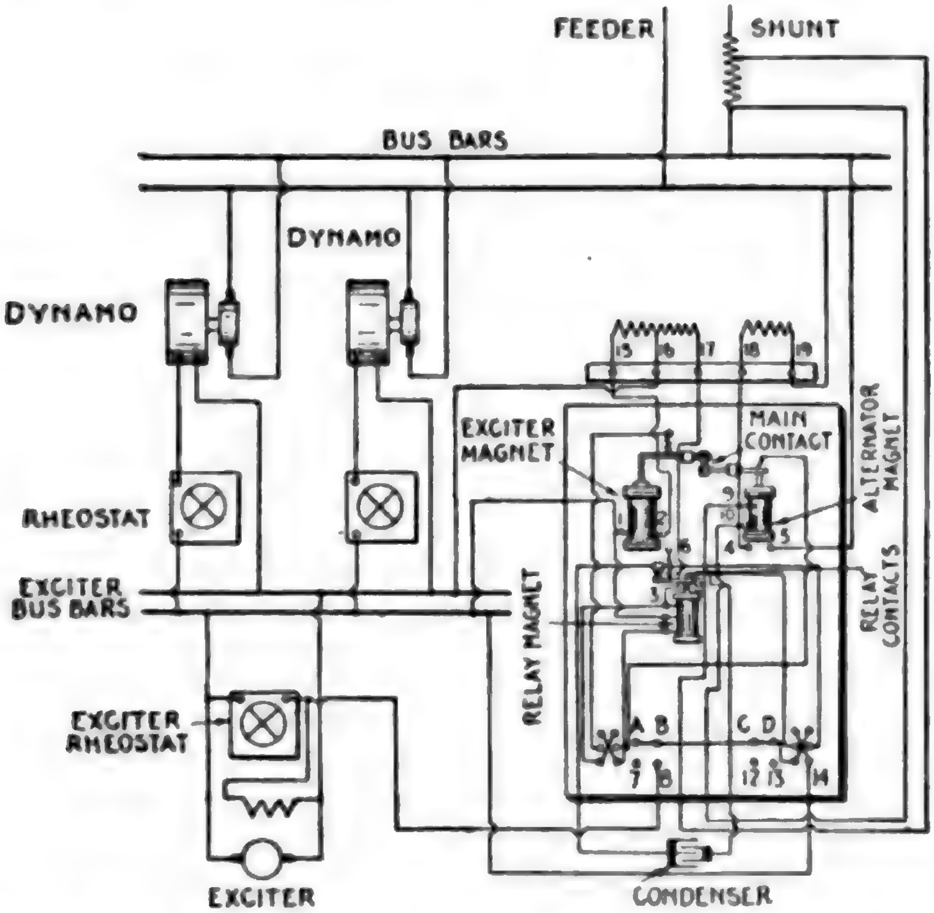

FEEDER
SHUNT
BUS BARS
DYNAMO
DYNAMO
RHEOSTAT
EXCITER BUS BARS
EXCITER RHEOSTAT
EXCITER
CONDENSER
EXCITER MAGNET
MAIN CONTACT
ALTERNATOR MAGNET
RELAY CONTACTS
RELAY MAGNET
15 16 17 18 19
A B C D
7 8 12 13 14

FIG. 2,451.—Diagram of connections of General Electric direct current voltage regulator (form T) with two dynamos and one exciter. In cases where several shunt or compound wound direct current machines are operating in parallel, either on two wire or three wire systems, a good arrangement for voltage regulation and line drop compensation is obtained by using this regulator and a separate exciter. The compensating shunt as well as pressure wires can be used to maintain a constant pressure at the center of distribution.

Ques. How is this automatic locking of the pawl obtained?

Ans. By having a lip G on the under side of the pawl strike a finger H fastened to the bearings in front of the ratchet wheel.

The pawl is thus raised just before it reaches the limit of its clockwis travel sufficient to be locked by its trigger.

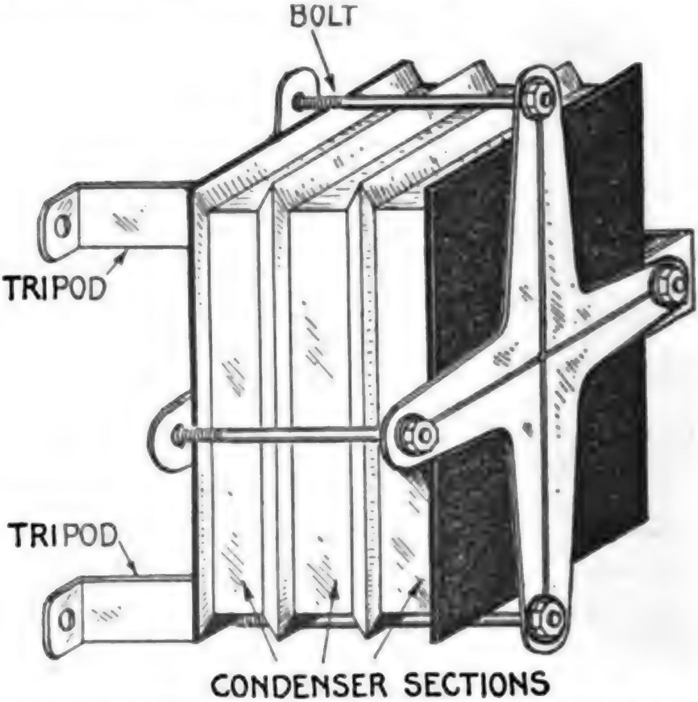


FIG. 2,452.—**Condenser sections** and method of assembling same with tripod. **The tripo bolts** are made of extra length to accommodate the addition of extra condenser section if necessary. The illustration shows three sections in position.

Ques. How does the mechanism operate when th voltage rises above normal?

Ans. As described above, with the exception that the righ hand trip causes a rotation of the regulator in the opposit direction.

Ques. How is adjustment made for various voltages

Ans. Taps are provided on the resistance in series with th relay, and finer adjustment can be obtained by means of the helical spring on the right hand end of the balance arm.

In order to adjust the sensitiveness of regulation, the bearing for the balance arm can be raised or lowered by means of a stud J, fig. 2,450, connecting this bearing with the bearing of the operating shaft, and the regulator can be made to maintain the voltage within 1 per cent. above or below normal.

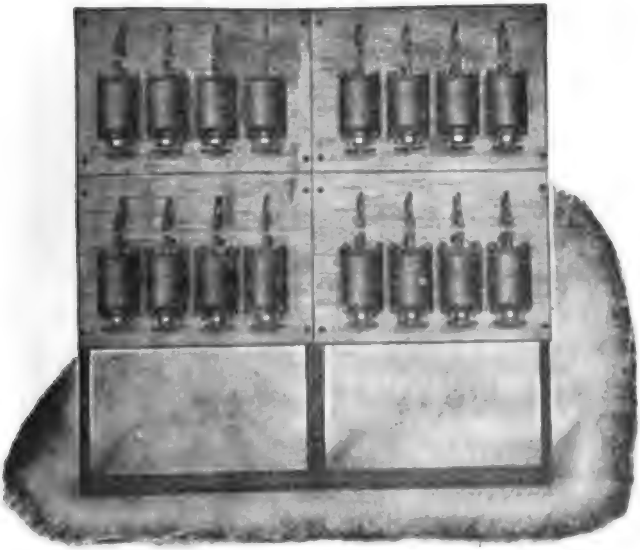
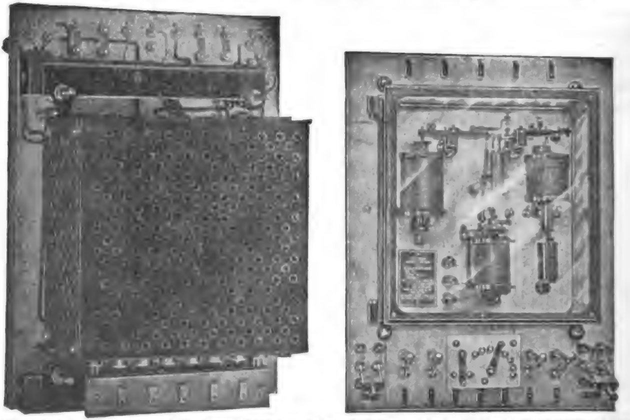


FIG. 2,453.—Westinghouse unit switch type pressure regulator, designed for handling heavy currents where a variable ratio transformer type of regulator is desired. The regulator consists of a number of electrically operated switches controlled from a master switch. These switches are arranged to perform practically the same cycle of operation as previously described for the drum type regulators. The transformer windings are divided into sections, and two floating coils are provided which are connected to various taps on the main auto-transformer. These floating coils have intermediate steps, and the successive operation of the switches connects the floating coils in proper sequence to the main auto-transformer, and transfers the line connection from one point of the floating coil to the next. In this way a 23 point regulator with sixteen switches, and a 71 point regulator with 21 switches may be supplied. The master switches are arranged with an automatic lock to prevent their being operated too rapidly. The magnet switches themselves are so interlocked that the proper sequence of operation is insured. The electrically operated switches may be of the open type, mounted on a slate or marble switchboard, when the whole control outfit is placed in a room which is comparatively free from dust or dirt of any kind, and where there is no danger of employees coming in contact with the switches. The other type of switch is entirely enclosed, the main contacts being oil immersed. The frames of these switches are grounded and the whole design is arranged to operate under ordinary dirty conditions. All of these switches, however, should receive the necessary inspection and attention. The contacts have a long life and are easily renewed. Regulators of this type are adapted for metallurgical purposes where the regulation is effected in the primary circuit and the secondary circuit is of very low voltage but large current capacity and is used for supplying power to the furnaces. These regulators have been built in capacities up to 800 amperes at 3,300 volts.

Ques. What provision is made for convenient inspection?

Ans. A snap switch is provided by means of which the power to the motor and relay can be disconnected.

Automatic Voltage Regulators for Alternators.—The accurate regulation of voltage on any alternating current system



FIGS. 2,454 and 2,455.—Front and rear views of General Electric automatic voltage regulator. The regulator has *a* **direct current** *control magnet, an* **alternating current** *control magnet, and a relay.* The **direct current control magnet** is connected to the exciter bus bars. This magnet has a fixed stop core in the bottom and a movable core in the top which is attached to a pivoted lever having at the opposite end a flexible contact pulled downward by four spiral springs. For clearness, however, only one spring is shown in the figure. Opposite the direct current control magnet is **the alternating current control magnet** which has a pressure winding connected by means of a pressure transformer to the alternator or bus bars. **There is an adjustable compensating winding** on the alternating current magnet connected through a current transformer to the principal lighting feeder. The object of this winding is to raise the voltage of the alternating current bus bars as the load increases. The alternating current control magnet has a movable core and a lever and contacts similar to those of the direct current control magnet, and the two combined produce what is known as the "floating main contacts." **The relay** *consists of a* **U** *shaped magnet core having a differential winding and a pivoted armature controlling the contacts which open and close the shunt circuit across the exciter field rheostat.* **One of the differential windings** of the relay is permanently connected across the exciter bus bars and tends to keep the contacts open; the other winding is connected to the exciter bus bars through the floating main contacts and when the latter are closed, neutralizes the effect of the first winding and allows the relay contacts to short circuit the exciter field rheostat. **Condensers** are connected across the relay contacts to prevent severe arcing and possible injury.

is of importance. The desired voltage may be maintained constant at the alternator terminals by rapidly opening and closing a shunt circuit across the exciter field rheostat.

Ques. Describe in more detail this method of regulation.

Ans. The rheostat is first turned in until the exciter voltage is greatly reduced and the regulator circuit is then closed. This short circuits the rheostat through contacts in the regulator and the voltage of the exciter and alternator immediately rise. At a predetermined point, the regulator contacts are automatically

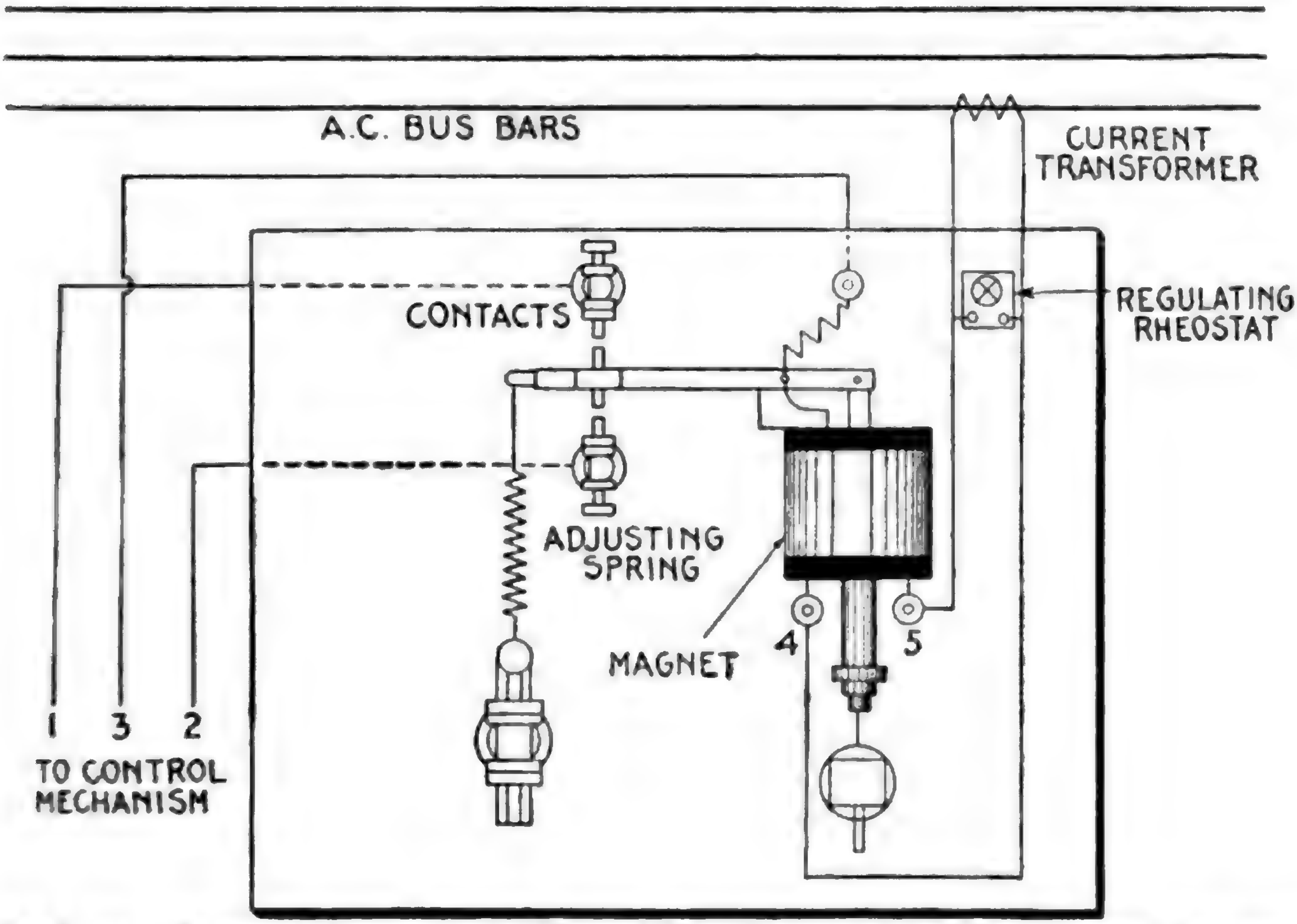


FIG. 2,456.—Diagram of connections of General Electric **contact making** ammeter for operating on alternating current circuits. *The instrument is designed to indicate* with the aid of a current transformer, *certain values of current in an alternating current system.* This value depends upon the setting of the regulating rheostat in parallel with the pressure coil of the ammeter. It is also possible with this instrument, together with the necessary control apparatus, to *hold* certain values of current. **By using a different magnet coil** this meter may be connected to a shunt instead of a current transformer and used on a direct current system.

opened and the field current of the exciter must again pass through the rheostat. The resulting reduction in voltage is arrested at once by the closing of the regulator contacts which continue to vibrate in this manner and keep the generator voltage within the desired limits. The connections are shown in fig. 2,457.

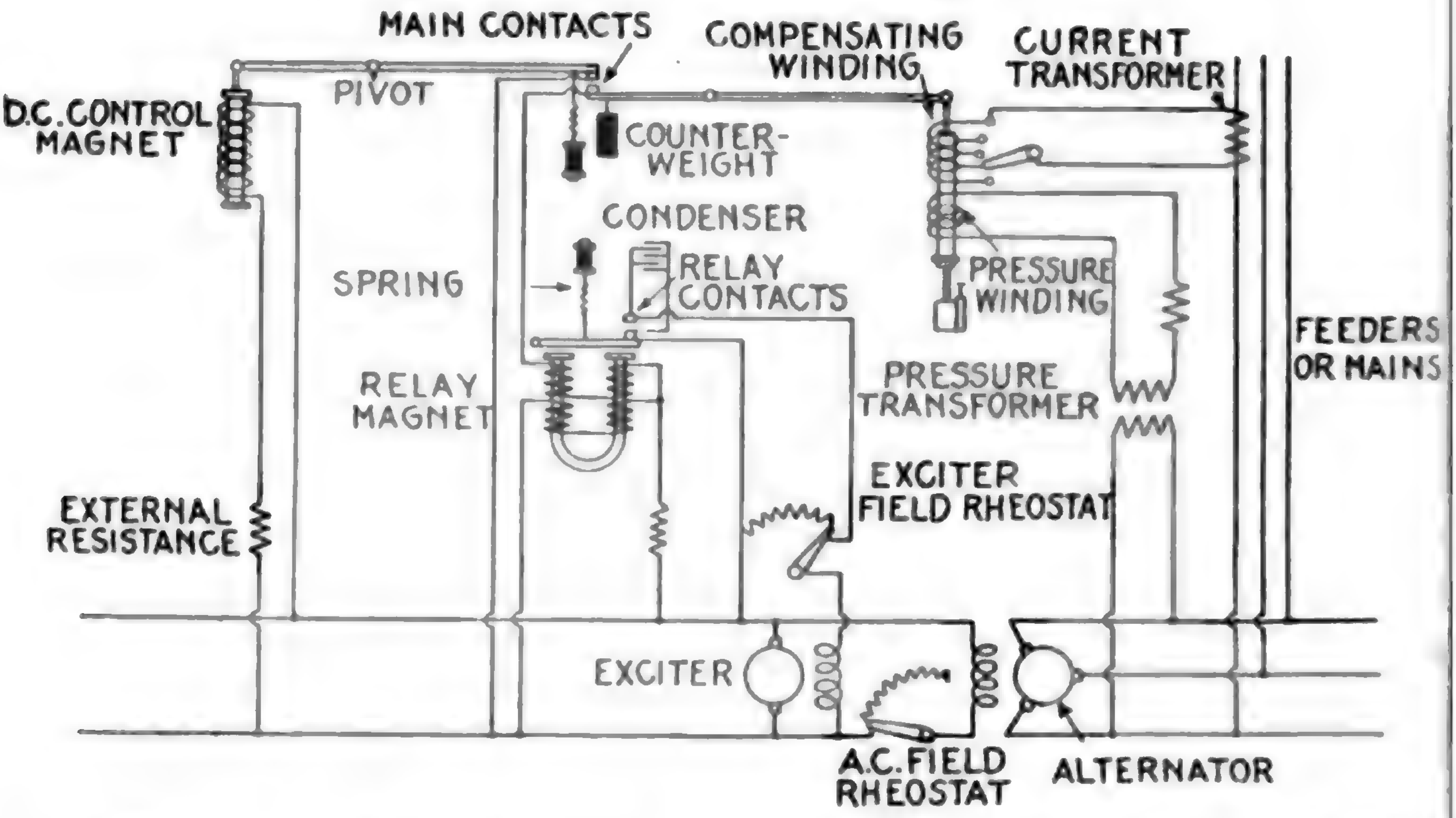

MAIN CONTACTS
COMPENSATING WINDING
CURRENT TRANSFORMER
D.C. CONTROL MAGNET
PIVOT
COUNTER-WEIGHT
CONDENSER
SPRING
RELAY CONTACTS
PRESSURE WINDING
FEEDERS OR MAINS
RELAY MAGNET
PRESSURE TRANSFORMER
EXCITER FIELD RHEOSTAT
EXTERNAL RESISTANCE
EXCITER
A.C. FIELD RHEOSTAT
ALTERNATOR

FIG. 2,457.—Diagram of General Electric automatic voltage regulator connections with alternator and exciter. **In operation,** the circuit shunting the exciter field rheostat through the relay contacts is opened by means of a single pole switch at the bottom of the regulator panel and the rheostat turned in until the alternating current voltage is reduced 65 per cent. below normal. This weakens both of the control magnets and the floating main contacts are closed. This closes the relay circuit and demagnetizes the relay magnet, releasing the relay armature, and the spring closes the relay contacts. The single pole switch is then closed and as the exciter field rheostat is short circuited, the exciter voltage will at once rise and bring up the voltage of the alternator. This will strengthen the alternating current and direct current control magnets, and at the voltage for which the counterweight has been previously adjusted, the main contacts will open. The relay magnet will then attract its armature and by opening the shunt circuit at the relay contacts will throw the full resistance into the exciter field circuit tending to lower the exciter and alternator voltage. The main contacts will then be again closed, the exciter field rheostat short circuited through the relay contacts and the cycle repeated. This operation is continued at a high rate of vibration due to the sensitiveness of the control magnets and maintains a steady exciter voltage.

Line Drop Compensators.—In order that the actual voltage at a distant point on a distribution system may be read at the station some provision must be made to *compensate* for the line drop, that is to say, for the difference in voltage between the alternator and the center of distribution.

In order to do this a device which is known as a "line drop compensator" is placed in the voltmeter circuit as shown in the diagram, fig. 2,458.

Ques. What are the essential parts of a line drop compensator?

Ans. The elements of a line drop compensator are a variable resistance, and a variable inductance.

Ques. Describe the connections.

Ans. The secondary of a pressure transformer is connected in series with the compensator inductance and resistance, and the secondary of a current transformer as shown in the diagram, fig. 2,458.

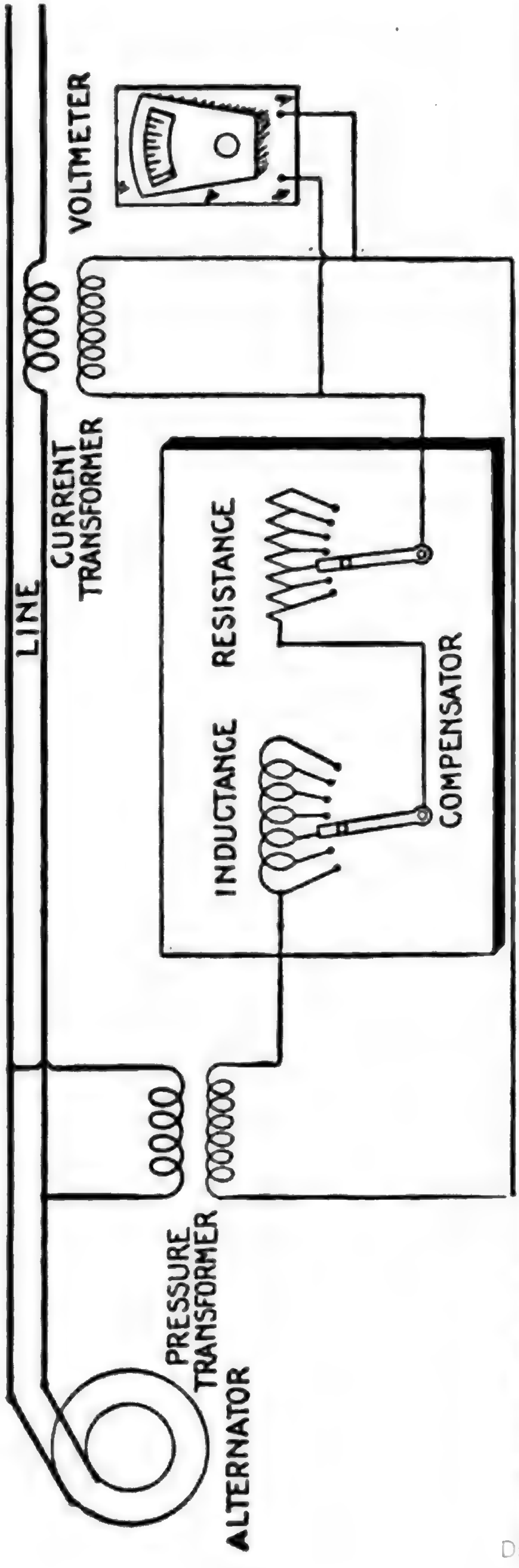


FIG. 2,458.—Diagram showing **essential parts and connections for a line drop compensator.** *The compensator corrects the voltmeter indication at the supply end of a feeder for the ohmic and inductive drop in pressure between that point and the point of consumption*, so that the reading of the station voltmeter corresponds with the actual voltage at the point of consumption, independent of the power factor and current. **It is especially useful** for adjusting pressure regulators.

Ques. How are the inductance and resistance wound?

Ans. They are wound so that any proportion of the winding of either can be put in or out of the voltmeter circuit.

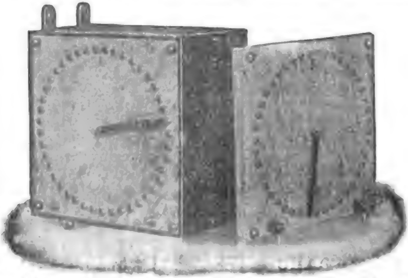


FIG. 2,459.—General Electric line drop compensator. It has two dial switches with many taps to the resistance and reactance in the box so that it can be adjusted to compensate accurately for line losses with loads of varying power factor. Dial R changes resistance, and dial X, reactance.

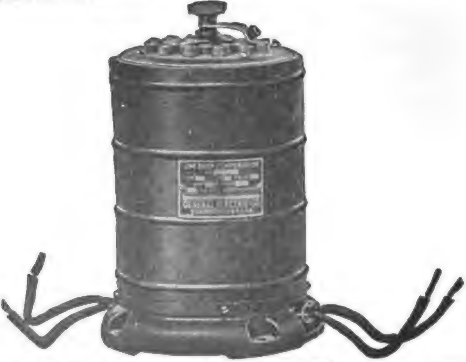


FIG. 2,460.—General Electric line drop compensator. This compensator contains besides resistance and inductance, a current transformer, the secondary of the transformer being connected in series with the resistance and inductance; the primary of the contained current transformer is connected to an external current transformer. The reactance and resistance are both so wound that any proportion of the winding can be cut in or out of the voltmeter circuit. Both elements have 12 points of adjustment of one volt each, giving a total combined drop at maximum setting of about 17 volts.

Ques. How can the voltmeter indicate the pressure at the center of distribution?

Ans. If the amount of inductance and resistance be properly adjusted, there will be produced a local circuit corresponding exactly in all its characteristics to the main circuit. Hence, any change in the main circuit produces a corresponding change in the local circuit, and causes the voltmeter to always indicate the pressure at the end of the line or center of distribution or at any point for which the adjustment is made.

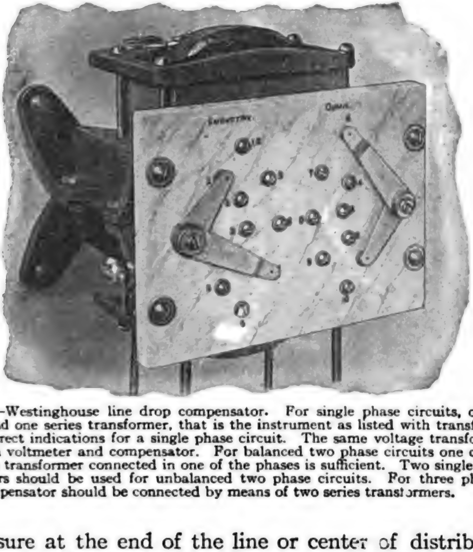


FIG. 2,461.—Westinghouse line drop compensator. For single phase circuits, one compensator and one series transformer, that is the instrument as listed with transformers, will give correct indications for a single phase circuit. The same voltage transformer serves for both voltmeter and compensator. For balanced two phase circuits one compensator and one transformer connected in one of the phases is sufficient. Two single phase compensators should be used for unbalanced two phase circuits. For three phase circuits the compensator should be connected by means of two series transformers.

Ques. How should the adjustment be made?

Ans. It is advisable to calculate the ohmic drop for full load and set the resistance arm at the point which will give the

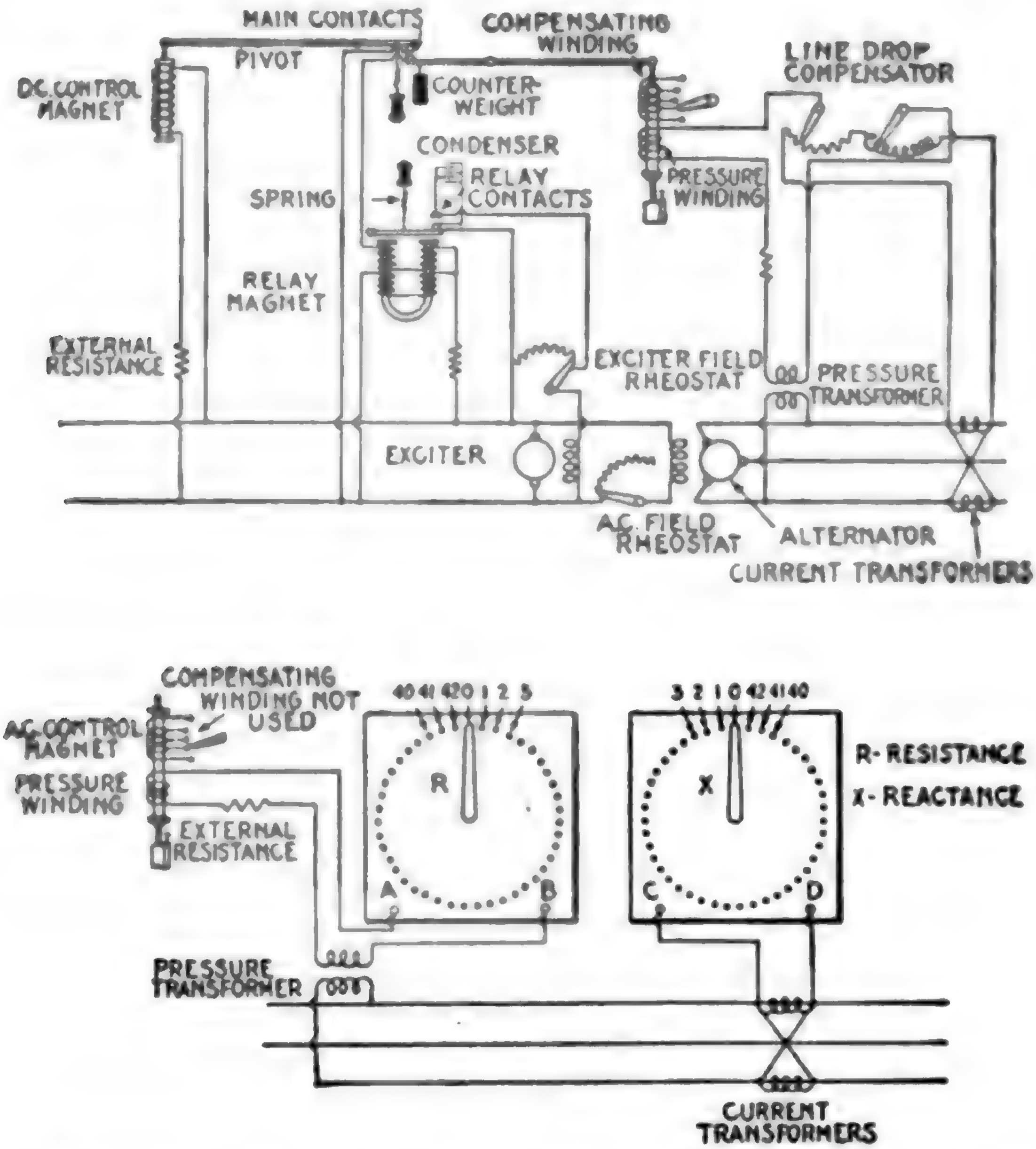

MAIN CONTACTS
PIVOT
COMPENSATING WINDING
LINE DROP COMPENSATOR
D.C. CONTROL MAGNET
COUNTER-WEIGHT
CONDENSER
RELAY CONTACTS
SPRING
PRESSURE WINDING
RELAY MAGNET
EXTERNAL RESISTANCE
EXCITER FIELD RHEOSTAT
PRESSURE TRANSFORMER
EXCITER
A.C. FIELD RHEOSTAT
ALTERNATOR
CURRENT TRANSFORMERS
COMPENSATING WINDING NOT USED
A.C. CONTROL MAGNET
PRESSURE WINDING
EXTERNAL RESISTANCE
40 41 42 0 1 2 3
3 2 1 0 42 41 40
R
X
A
B
C
D
R-RESISTANCE
X-REACTANCE
PRESSURE TRANSFORMER
CURRENT TRANSFORMERS

FIG. 2,462.—Diagram of **automatic voltage regulator, using line drop compensator.** For ordinary installations the compensating winding on the alternating current control magnet is connected to a current transformer in the main feeder. A dial switch is provided by which the strength of the alternating current control magnet can be varied and the regulator made to compensate for any desired line drop up to 15 per cent, according to the line requirements. Where the power factor of the load has a wide range of variation, a special line drop compensator, such as shown in fig. 2,459, adapted to the regulator would be desirable. The connections are readily understood by the diagram. The number of condenser sections which will prevent undue arcing at the relay contacts depends on the characteristics of the exciter. They may be roughly estimated by allowing one section for each 15 kw. capacity for exciters with laminated poles, and one for each 22 kw. capacity for exciters with solid steel poles. It is necessary though to have one condenser section for each pair of relay contacts, and at times it becomes necessary to apply a double section for each pair of contacts. In the lower part of the figure the line drop compensation and connections is reproduced in more detail on a larger scale.

NOTE.—It is desirable, in any system of distribution, to read the active voltage at the point of distribution, by means of the voltmeters in the station. A compensator proper consists of a variable resistance and a variable inductance, and sometimes a current transformer. In wiring, the voltmeter, instead of being connected directly across the secondaries of a pressure transformer, has inserted in series with it, portions of the resistance and inductance of the compensator. These are so connected that the drop in pressure across them will be combined with that of the pressure transformer, so that the voltmeter reading indicates the pressure at the center of distribution or end of the line.

required compensation and then adjust the inductance arm until the voltmeter reading corresponds to the voltage at the point on the line selected for normal voltage.

Starting Compensators.—These are used for starting induction motors and consist of inductive windings (one for each phase) with a number of taps connecting with switch contacts as shown in fig. 2,463. A starting compensator is similar to a rheostat except that inductive windings are used in place of the resistance grids.

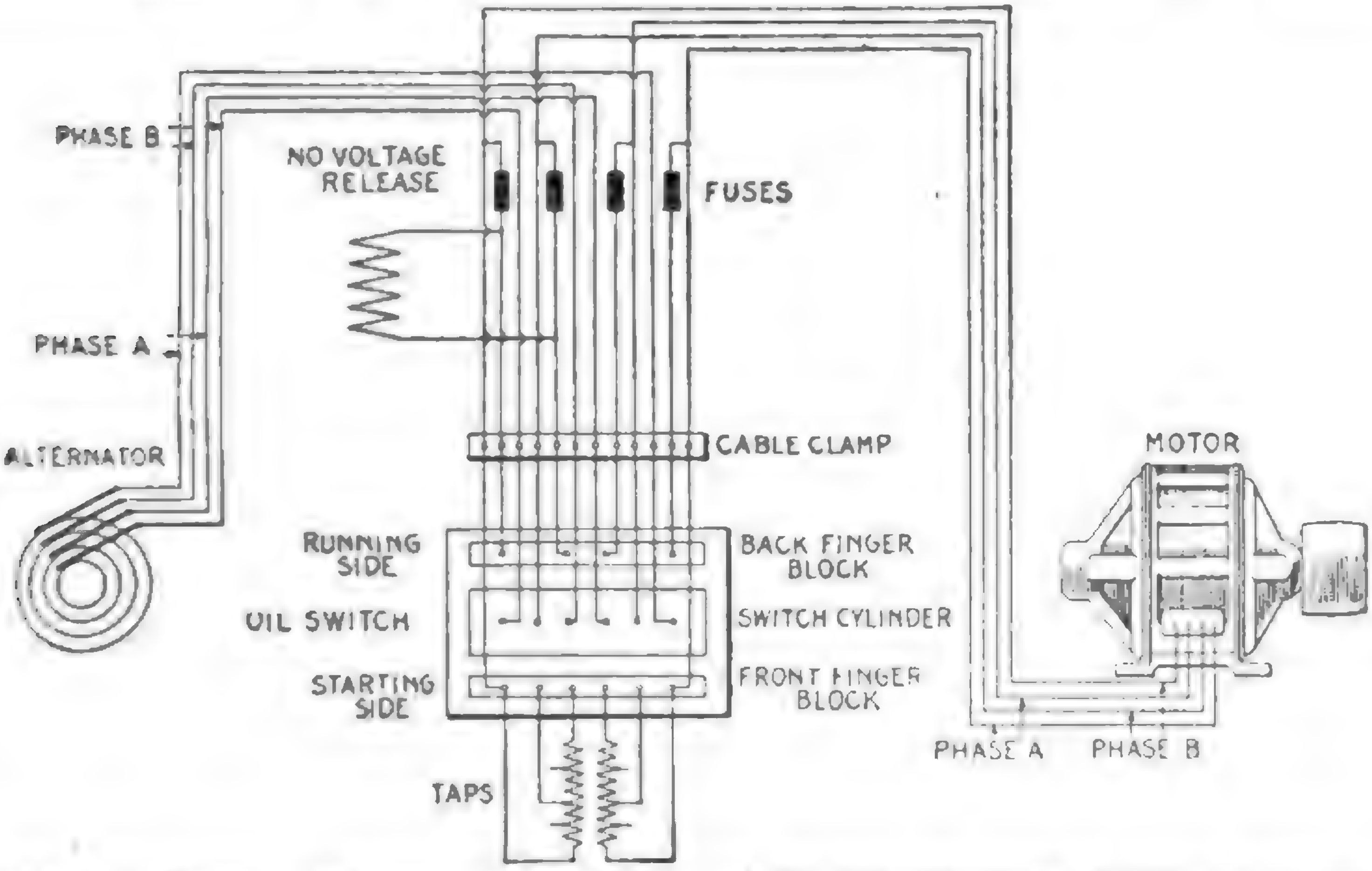

PHASE B
NO VOLTAGE RELEASE
FUSES
PHASE A
ALTERNATOR
CABLE CLAMP
MOTOR
RUNNING SIDE
BACK FINGER BLOCK
OIL SWITCH
SWITCH CYLINDER
STARTING SIDE
FRONT FINGER BLOCK
PHASE A
PHASE B
TAPS

FIG. 2,463.—Diagram of connections of General Electric two phase starting compensator with no voltage release and fuses.

Ques. Describe the inductive windings.

Ans. The compensator winding consists of an inductive coil in each phase with each coil placed on a separate leg of a aminated iron core. Each coil is provided with several taps so located that a number of sub-voltages may be obtained.

Ques. Are starting compensators necessary for small motors? Why?

Ans. No, because the full voltage starting current taken, although equal to several times the load current, is nevertheless so small, compared with the capacity of the station

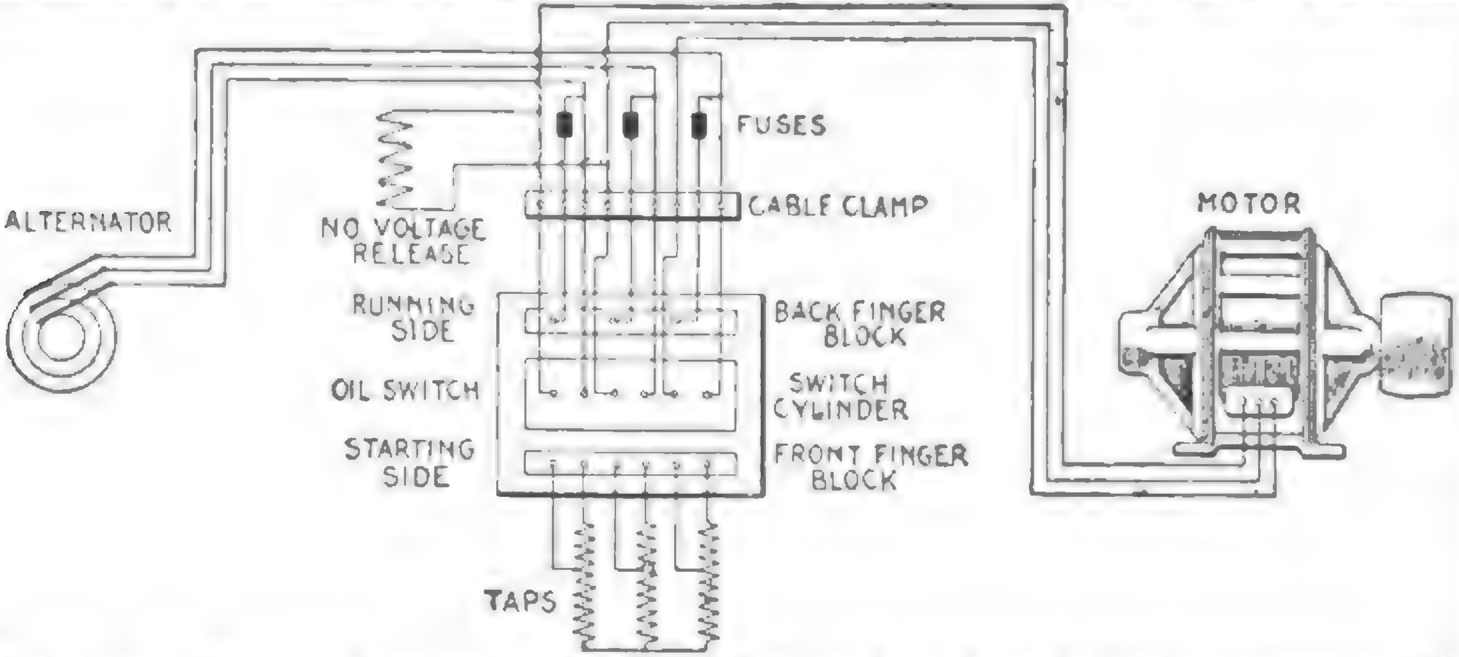

FUSES
ALTERNATOR
NO VOLTAGE RELEASE
CABLE CLAMP
MOTOR
RUNNING SIDE
BACK FINGER BLOCK
OIL SWITCH
SWITCH CYLINDER
STARTING SIDE
FRONT FINGER BLOCK
TAPS

FIG. 2,464.—Diagram of connections of General Electric three phase starting compensator with low voltage release and fuses.

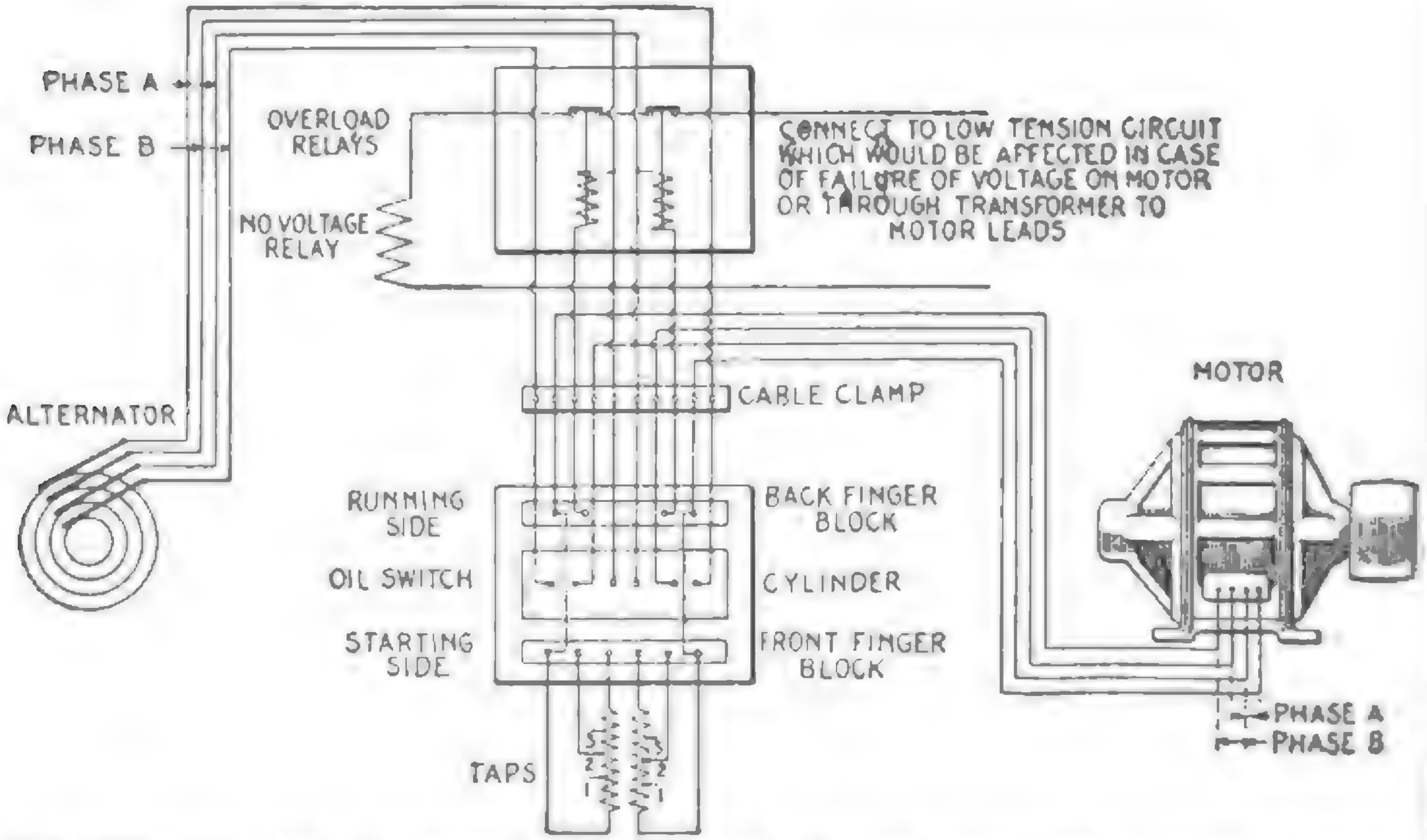
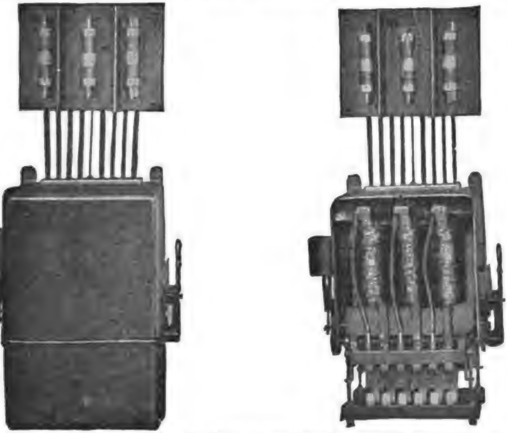

PHASE A
PHASE B
OVERLOAD RELAYS
NO VOLTAGE RELAY
CONNECT TO LOW TENSION CIRCUIT WHICH WOULD BE AFFECTED IN CASE OF FAILURE OF VOLTAGE ON MOTOR OR THROUGH TRANSFORMER TO MOTOR LEADS
ALTERNATOR
CABLE CLAMP
MOTOR
RUNNING SIDE
BACK FINGER BLOCK
OIL SWITCH
CYLINDER
STARTING SIDE
FRONT FINGER BLOCK
TAPS
PHASE A
PHASE B

FIG. 2,465.—Diagram of connections of General Electric two phase starting compensator with no voltage release and overload relays for 1,040 to 2,500 volt circuits.

alternators or feeders, that it does not materially affect the regulation of the circuit.

Motors larger than about 7 horse power cause an objectionably heavy rush of current if thrown directly on the line. Starting compensators obviate such sudden variations of line load and are accordingly recommended for motors above 7 horse power except in cases where voltage variations and excessive starting currents are not objectionable.



FIGS. 2,466 and 2,467.—General Electric **three phase hand operated starting compensator** Fig. 2,466, compensator in case; fig. 2,467, compensator with case removed. **The compensator consists of** *a core and windings, a cable clamp, and a switch, assembled in a substantial metal case with external operating handle and release lever.* **The windings** consist of coils wound on separate legs of a laminated core, and tapped at several points, the connections terminating at the switch contacts. The shaft of the switch extends through the sides of the compensator case, and is operated by a lever at the right, being held in the running position by a lever at the left. It is provided with wiping contacts. The switch is immersed in oil, and is intended to be used as a line switch as well as for starting the motor. **The lever has three positions**: "off," "starting," and "running." **In the *off* position,** *both compensator and motor windings are disconnected from the line.* **In the starting position,** *the switch connects the line to the ends and the motor to the taps of the compensator winding* without overload relays or fuses in circuit. **In the running position,** *the compensation winding is cut out and the motor is connected to the line through suitable fuses or overload relays* mounted directly above the compensator. To prevent the attendant throwing the motor directly on the line, and thereby causing a rush of current which it is the object of the compensator to avoid, an automatic latch is provided and so arranged that the lever at *off* position can be thrown only into the *starting position* (backward); and can be thrown thence into the *running position* (forward) only by a quick throw of the lever, whereby any appreciable drop in speed and consequent increase in current in passing from the starting into the running position is avoided

Ques. What should be noted with respect to the compensator winding taps?

Ans. The choice of a tap giving so low a voltage as to require over one minute for starting should be avoided so as to prevent the overheating to which starting compensators, in common with other motor starting devices, are liable if left in circuit unnecessarily long, or if the motor be started several times in rapid succession.

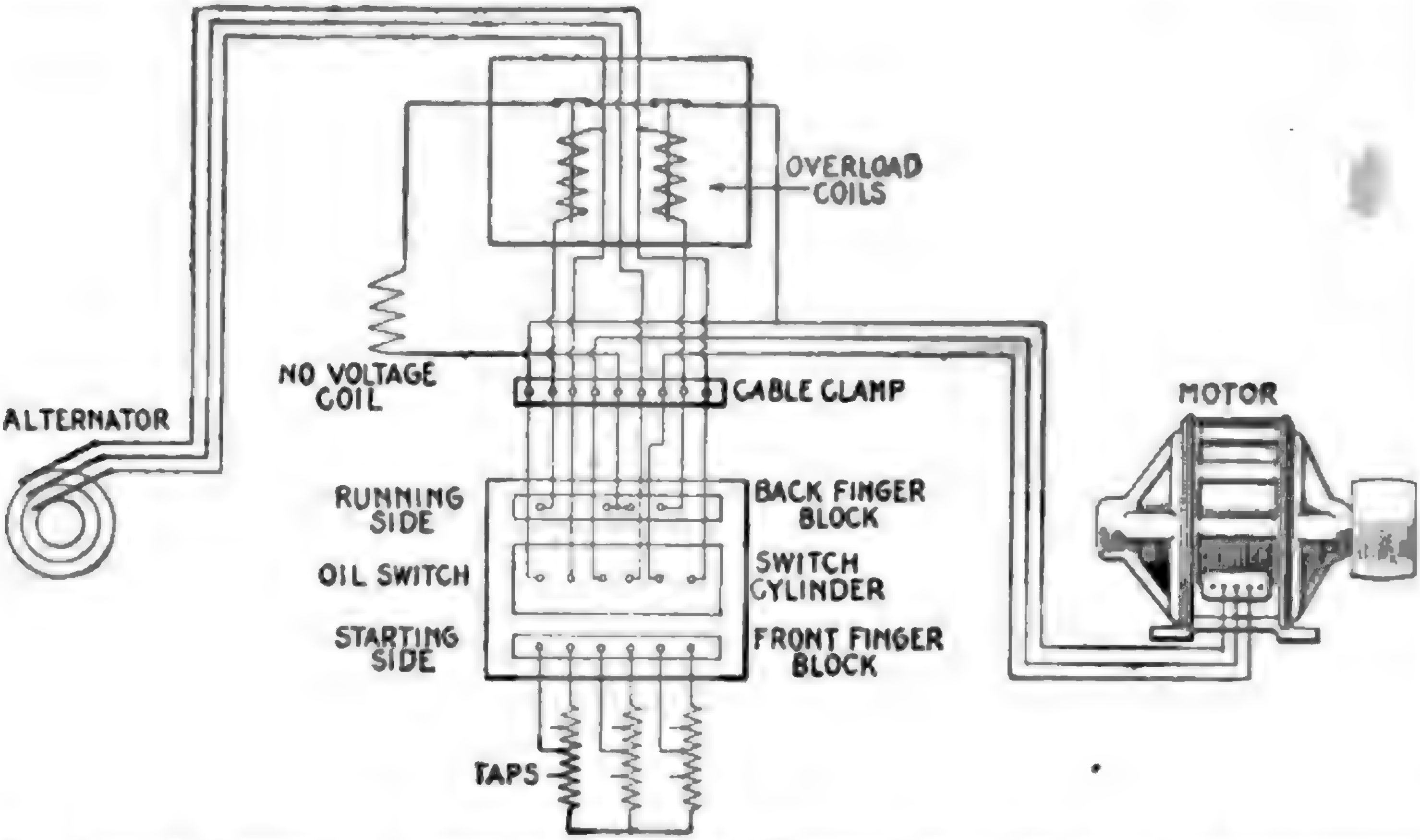

OVERLOAD COILS
NO VOLTAGE COIL
CABLE CLAMP
ALTERNATOR
MOTOR
RUNNING SIDE
BACK FINGER BLOCK
OIL SWITCH
SWITCH CYLINDER
STARTING SIDE
FRONT FINGER BLOCK
TAPS

FIG. 2,468.—Diagram of connections of General Electric three phase starting compensator with no voltage release and overload relays.

It should also be noted that the starting current diminishes rapidly as full speed is approached. It is, therefore, important that the switch be kept in the starting position until the motor has finished accelerating to prevent any unnecessary rush of current when the switch is thrown to the running position.

Ques. What is the usual arrangement of starting compensators for large motors?

Ans. Starting compensators may be wound for any voltage

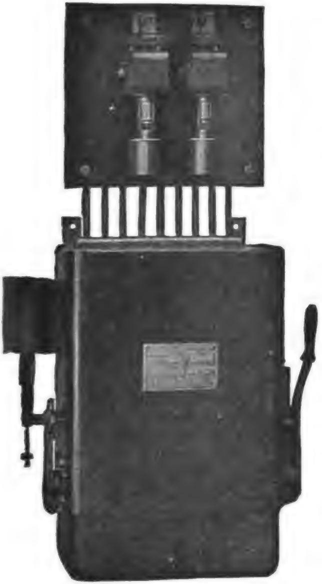


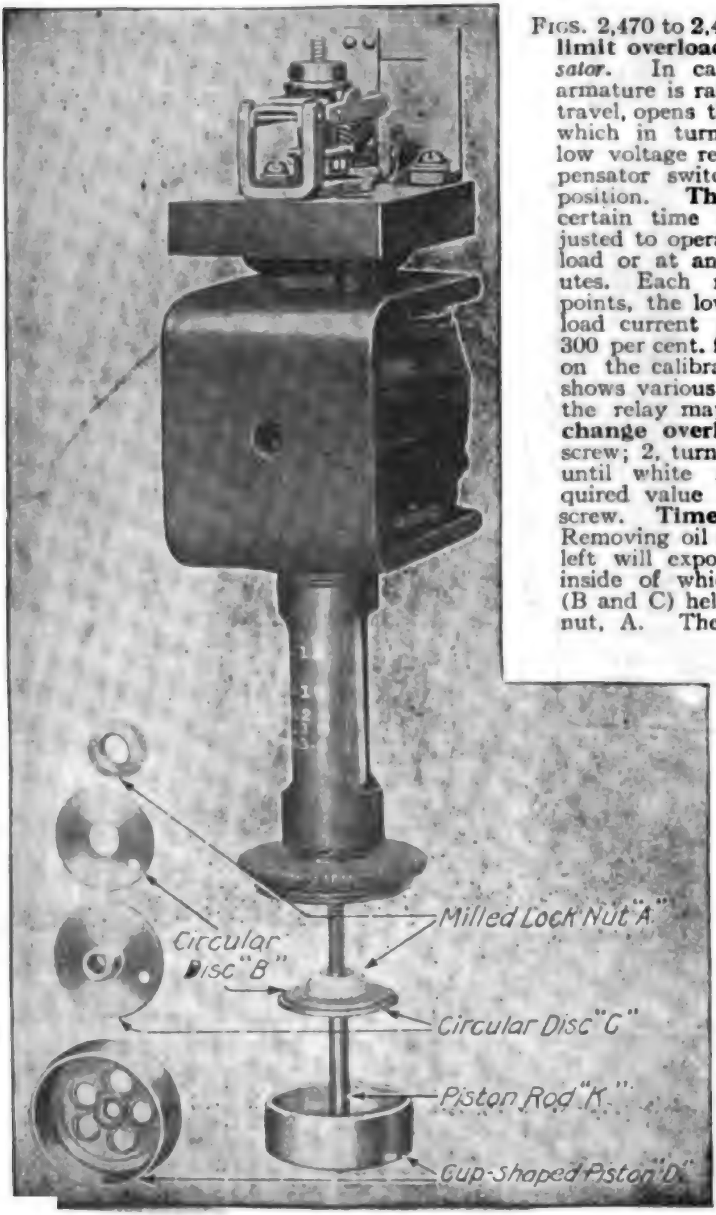
FIG. 2,469.—General Electric starting compensator with low voltage release and overload relays. On the switch shaft there are mounted two levers, held together with a strong spring which operates in either direction and prevents the switch being left on the starting position. On the running side it is held by the external low voltage release lever until released either by hand or by the action of a low voltage relay. The low voltage release consists of a cast iron frame open at the bottom and totally enclosing the coil. A laminated plunger is used to hold the tripping lever, the latter engaging with the lever mounted on the switch shaft. The compensator cannot be thrown into the running position without first going to the starting position and it cannot be left on the starting position.

or current for which it is practicable to build motors. For very large motors the switching device is generally separate from the compensator itself and consists of triple and four pole switches for three phase and two phase motors respectively. One double throw switch or two interlocked single throw switches are required for the motor and a single throw switch for energizing the compensator, the running side of the motor circuit being provided with fuses or automatic circuit breakers, or the switches provided with low voltage and overload release attachments.

Star Delta Switches.—These are starting switches, designed for use with small three phase squirrel cage motors having their windings so arranged that they may be connected in star for starting and in delta for running.

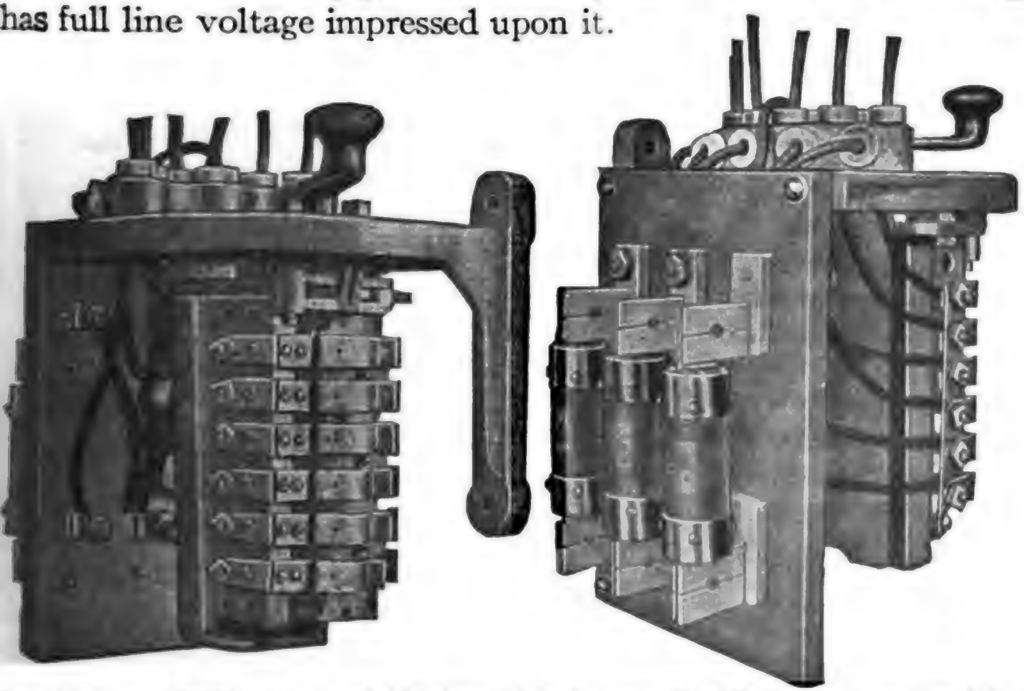
Ques. Describe the operation of a star delta switch.

Ans. In starting the motor, the drum lever is thrown in the starting direction which connects the field windings of the motor **in star.** When the motor has accelerated and has come partially up to speed the starting lever is quickly thrown to the running position in which position the field windings are connected **in**



FIGS. 2,470 to **2,474.**—General Electric **time limit overload relay** *for starting compensator.* In case of overload, the relay armature is raised and at the end of its travel, opens the small switch at the top which in turn opens the circuit of the low voltage release coil causing the compensator switch to return to the "off" position. **The oil dash pot** provides a certain time element and can be adjusted to operate immediately upon overload or at any interval up to five minutes. Each relay has five calibrating points, the lowest being the normal full load current of the motor, the highest 300 per cent. full load current. The scale on the calibration tube reads direct and shows various values of current at which the relay may be set to operate. **To change overload setting:** 1, loosen set screw; 2, turn relay plunger on piston rod until white mark comes opposite required value of current; 3, tighten set screw. **Time element adjustment:** Removing oil dash pot by turning to the left will expose the cup shaped piston, inside of which are two concentric discs (B and C) held together by a milled lock nut, A. There is a hole in each disc through which the oil must pass when the plunger of the relay is raised. The time element may be varied by changing the size of the opening between these discs, that is, to have the relays operate in a shorter period of time, increase the size of the opening and vice-versa. **To change the time setting:** 1, remove the oil dash pot; 2, raise the discs B and C on the piston rod; 3, loosen the lock nut A; 4, change the opening between B and C, giving a larger opening for shorter time of operation, and a smaller opening for longer time; 5, tighten lock nut A; 6, replace discs in piston D; 7, replace oil dash pot.

delta. The effect of connecting the field winding in star at starting is to reduce the voltage applied to each phase winding, while in the running position each phase of the field winding has full line voltage impressed upon it.



IGS. 2475, and 2,476.—Front and side views (oil tank removed) of Cutler-Hammer **star delta switch** *for starting small three phase squirrel cage motors.* **In construction,** the switch consists of one set of stationary fingers and a rotating wooden cylinder, carrying two sets of contacts. These parts are supported from the switch frame casting and are enclosed in a steel tank which contains an insulating oil. Flexible oil proof cable leads are brought out through insulated bushings in the top of the switch and tagged for convenience in connecting to the lines and motor. To prevent seepage of oil, the leads are sealed into the top of the cover with an oil proof sealing wax. The lever of the star delta switch is arranged with an interlock which prevents its being thrown directly into the running position from the off position. It is necessary to throw the lever first into the starting position and then with an uninterrupted movement to the running position. The circuit of the motor is broken only for an instant in changing from star to delta and no heavy inrush current occurs. **No voltage release** protection is provided by a latching solenoid which holds the spring centered drum cylinder in the running position. The no voltage release coil is mounted in the lower part of the starting switch, immersed in the oil tank, and is protected against mechanical injury and grounding. The coil is in circuit during the running period only and requires not more than 8 to 15 watts to hold the switch in the running position. The operation of this protective device is such that on failure of voltage the star delta switch will immediately be returned to the off position. **Overload release** protection consists of two relays on a small slate panel, which is mounted directly on the side of the star delta switch. The switch contacts of the overload release are connected in series with the connections to the no voltage release coil so that when an overload occurs the overload relay operates to open the circuit to the no voltage release coil, thus permitting the switch lever to return to the off position. The overload relays do not afford overload protection during the starting period, and when such protection is desired starting fuses should be installed. These fuses, if used, should have a capacity of 250 to 300 per cent. of the normal full load current of the motor.

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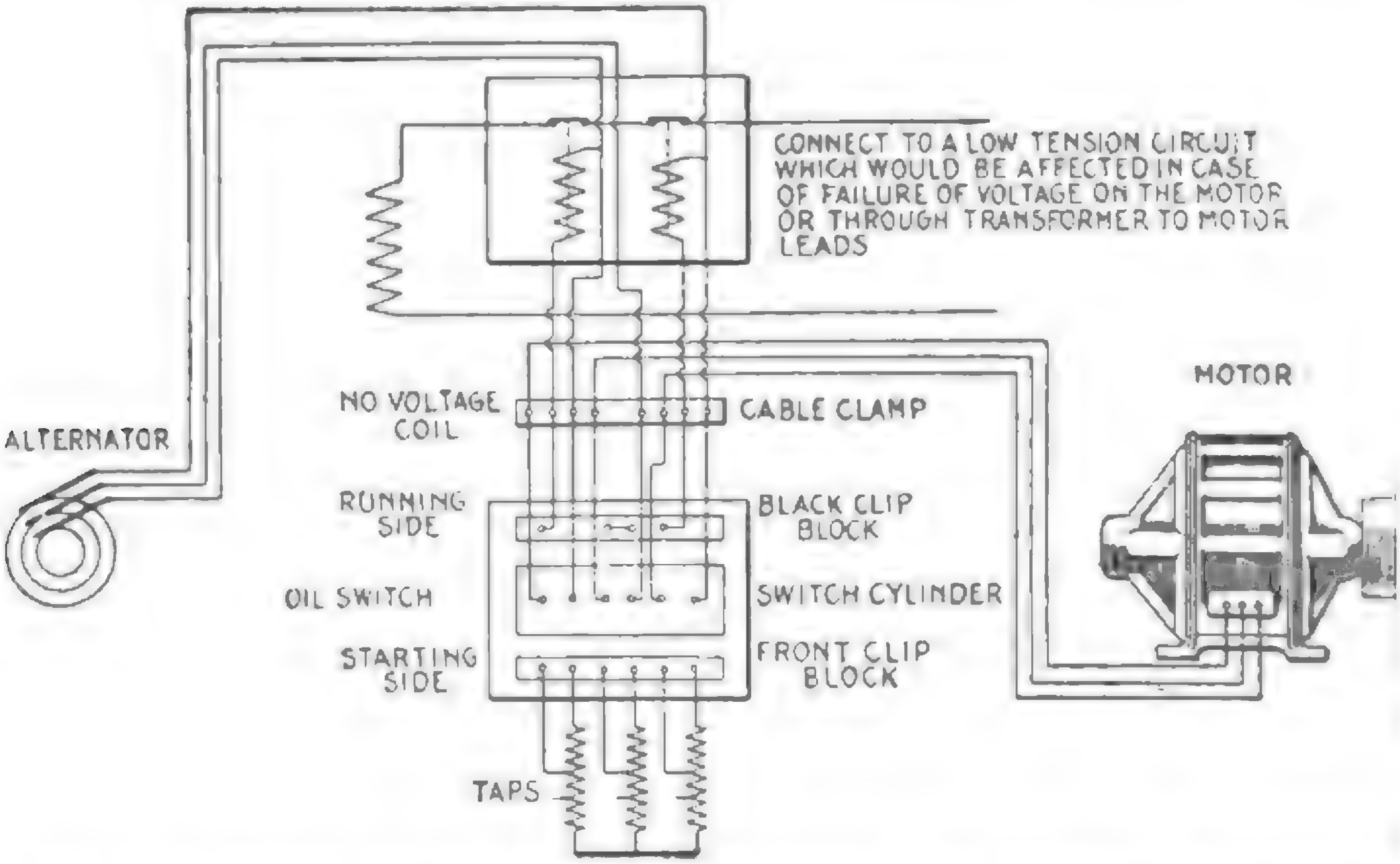

CONNECT TO A LOW TENSION CIRCUIT WHICH WOULD BE AFFECTED IN CASE OF FAILURE OF VOLTAGE ON THE MOTOR OR THROUGH TRANSFORMER TO MOTOR LEADS
MOTOR
NO VOLTAGE COIL
CABLE CLAMP
ALTERNATOR
RUNNING SIDE
BLACK CLIP BLOCK
OIL SWITCH
SWITCH CYLINDER
STARTING SIDE
FRONT CLIP BLOCK
TAPS

FIG. 2,477.—Diagram of connections of General Electric three phase starting compensat with low voltage release and overload relays for 1,040–2,500 volt circuits.

CHAPTER LXI

SYNCHRONOUS CONDENSERS

Synchronous Condensers.—A synchronous motor when sufficiently excited will produce a leading current, that is, when over excited it acts like a great condenser, and when thus operated on circuits containing induction motors and similar apparatus for the purpose of improving the power factor it is called a *synchronous condenser.*

Although the motor performs the duty of a condenser it possesses almost none of the properties of a stationary condenser other than producing a leading current, and is free from many of the inherent defects of a stationary condenser.

The relation of power factor to the size and efficiency of prime movers, generators, conductors, etc., and the value of synchronous condensers for improving the power factor is generally recognized.

Induction motors and other inductive apparatus take a component of current which lags behind the line pressure, and hereby lowers the power factor of the system, while a non-nductive load, such as incandescent lamps, takes only current n phase with the voltage and operates at unity power factor.

Since transformers require the magnetizing current, they may eriously affect the power factor when unloaded or partially oaded, but when operating at full load their effect is practically egligible.

The relative effect of fully loaded and lightly loaded induction motors on the power factor is indicated by the diagram, fig. 2,478. The magnetizing current is nearly constant at all loads and is wattless, lagging 90 degrees behind the impressed pressure, or at right angles to the current which is utilized for power.

In the figure, AB is the magnetizing component, which is always wattless, and CB the power component. The angle ACB gives the phase relation between voltage and current; the cosine of this angle CB ÷ AC is the power factor.

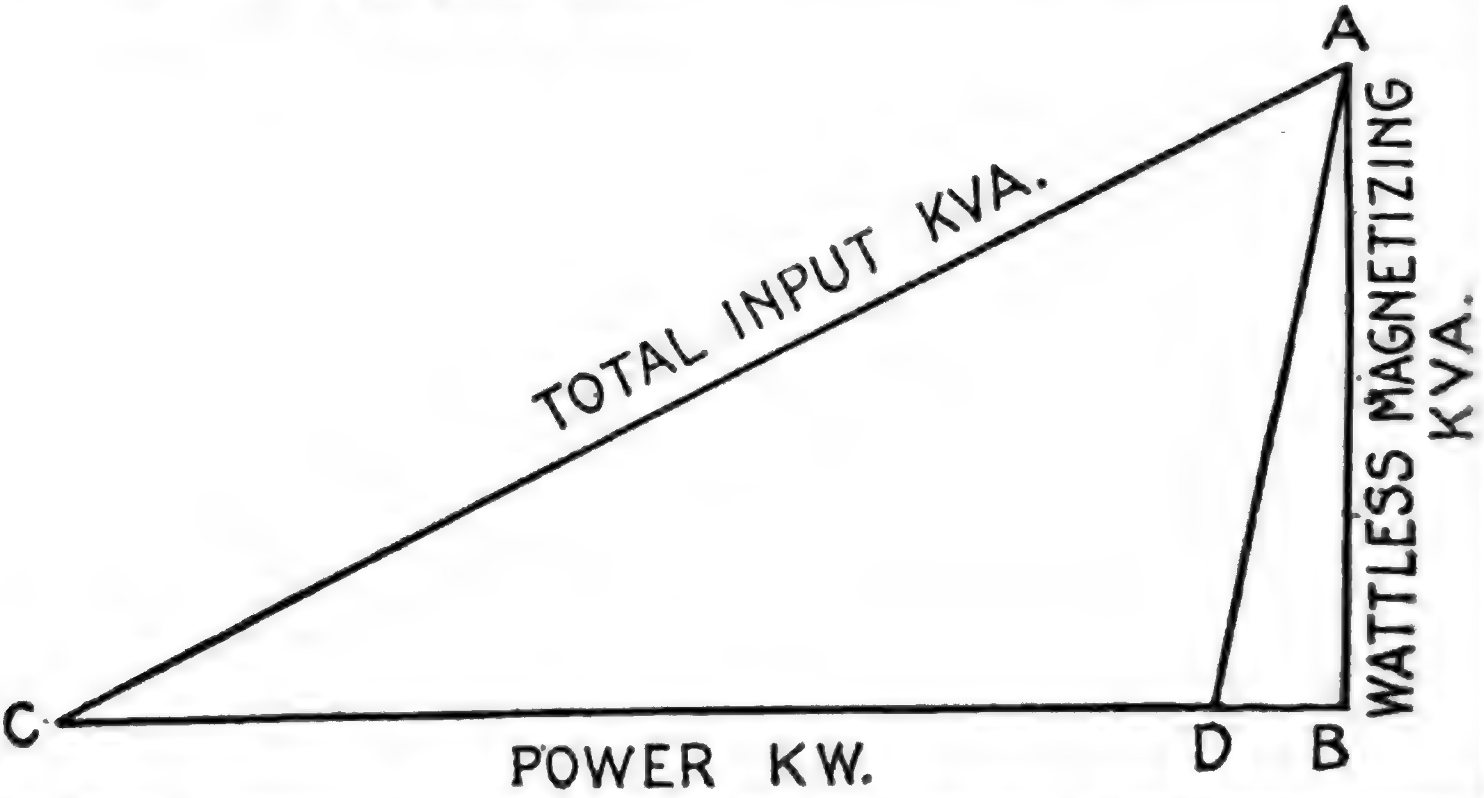


FIG. 2,478.—Diagram showing relative effect of fully loaded and lightly loaded induction motors on power factor.

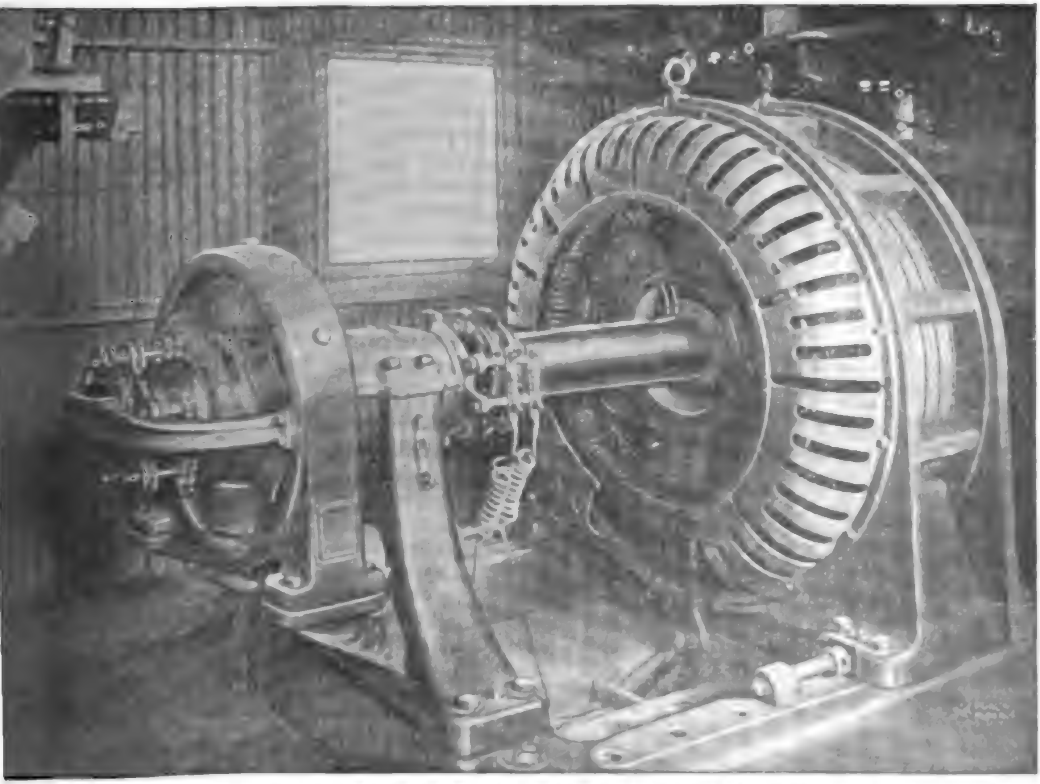
It is evident from the diagram that if the load be reduced, the side CB is shortened, and as AB is practically constant, the angle of lag ACB is increased. It therefore follows that the cosine of this angle, or the power factor is reduced.

The figure clearly shows the reason for the low power factor of induction motors on fractional loads and also shows that since the magnetizing current is practically constant in value, the induction motor can never operate at unity power factor.

With no load, the side CB (real power) is just sufficient to supply the friction and windage. If this be represented by DB, since AB remains constant, the power factor is reduced to 10 or 15 per cent. and the motor takes from the line about 30 per cent. of full load current. It therefore follows that a group of lightly loaded induction motors can take from the system a large current at exceedingly low power factor.

The synchronous motor when used as a condenser, as before stated, has the property of altering the phase relation between pressure and current, the direction and extent of the displacement being dependent on the field excitation of the condenser.

It can be run at unity power factor and minimum current input, or it can be over excited and thereby deliver leading current



G. 2,479.—General Electric 400 kw., 550 volt, 600 R.P.M., **synchronous condenser** with direct connected exciter installed in sub-station No. 1 of the Colorado Light & Power Co., Cripple Creek, Colo. The machine is designed for alternating current starting by means of a compensator. The field is provided with a standard synchronous motor winding, and, in addition, an amortisseur winding which assists in starting and serves as a damping device to minimize hunting.

hich compensates for the inductive load on other parts of the stem. The synchronous condenser, therefore, can supply agnetizing current to the load on a system while the power mponent is supplied by the generators.

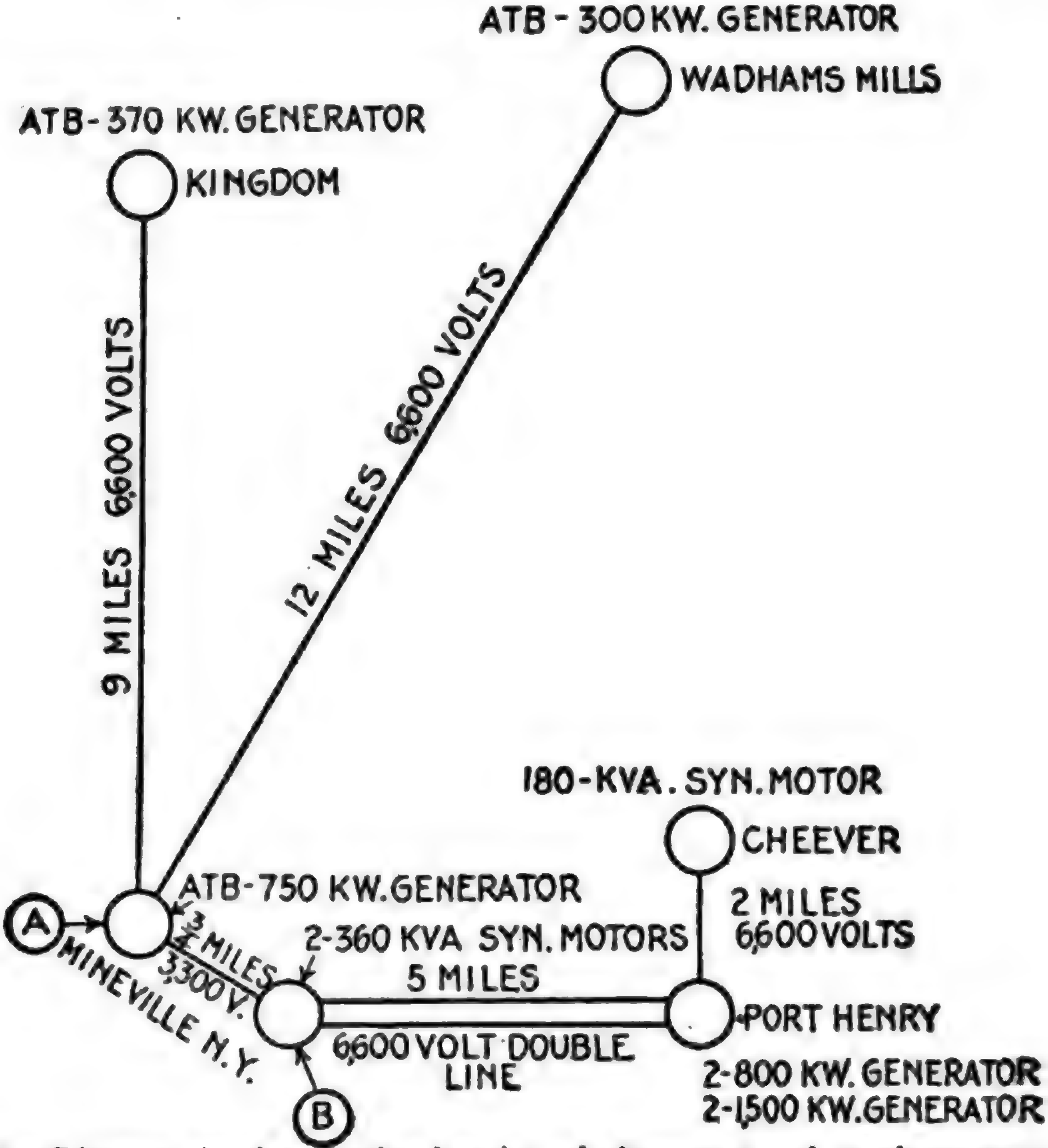

ATB - 300 KW. GENERATOR
WADHAMS MILLS
ATB - 370 KW. GENERATOR
KINGDOM
9 MILES 6,600 VOLTS
12 MILES 6,600 VOLTS
180-KVA. SYN. MOTOR
CHEEVER
2 MILES
6,600 VOLTS
ATB-750 KW. GENERATOR
A
3/4 MILES
3,300 V.
MINEVILLE N.Y.
2-360 KVA SYN. MOTORS
5 MILES
6,600 VOLT DOUBLE LINE
PORT HENRY
2-800 KW. GENERATOR
2-1,500 KW. GENERATOR
B

Fig. 2,480.—Diagram showing relative location of alternators and synchronous motors plant of Witherbee Sherman & Co., Mineville N. Y. The distribution system of the Com pany is provided with three synchronous motors, as shown. The system includes tw hydro-electric, one turbine driven, and one engine driven generator plants; from three these, current is transmitted to the fourth, which is located in Mineville, at the point "A" the current being distributed to the motor circuits from the points "A" and "B." Th transmission to the central station at Mineville is over three phase circuits at 6,600 volts. For operating the mine at Cheever, current is transmitted direct from the generatin station at Port Henry. The distribution from "A" and "B" is all at 3,300 volts, bein stepped down to 440 volts for the operation of the motors, which have a total rated capa ity of 4,762 horse power. Excepting three synchronous motors, the load is practically inductive, there being less than 10 kw. required for lighting. The actual power deman ranges from 60 to 65 per cent. of the rated motor capacity, and prior to the installatio of the synchronous motors, the power factor was approximately 68 per cent., the co denser effect of these motors making it possible to maintain an average of about 90 p cent. power factor in spite of the fact that a considerable portion of the induction mot load is very widely distributed. The three synchronous motors are partially loaded, ea motor driving an air compressor through belting. The 180 kva. motor at Cheever tak about 150 kw. for the operation of a 1,250 cubic foot compressor, while the two 360 k machines take about 300 kw. each, for the operation of two 2,500 cu. ft. sets. Th operation of these compressors affords a method of utilizing a portion of the motor capa ity mechanically, inasmuch as the load on the motors is practically constant during th time the mines are in operation, and thereby permit the motors to be run at approximate 90 per cent. power factor.

Effects of Low Lagging Power Factors.—Transformers are rated in kva. output; that is, a 100 kva. transformer is supposed to deliver 100 kw. at unity power factor at normal voltage and at normal temperatures; but, if the power factor should be, say .6 lagging, the rated energy output of the transformer would be only 60 kw. and yet the current and, consequently, the heating would be approximately the same as when delivering 100 kw. at unity power factor.

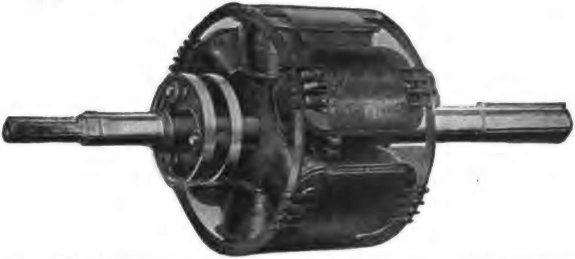


FIG. 2,481.—Field of a synchronous condenser Note the **amortisseur winding,** *erroneously* called ***squirrel cage*** **winding,** consisting of two end rings which serve to short circuit spokes passing through the pole tips as shown. **The amortisseur winding** *assists in* **starting** *and serves also as a damping device to minimize* **hunting.**

The regulation of transformers is inherently good, being for small lighting transformers about 1½ to 2 per cent. for a load of unity power factor, and about 4 to 5 per cent. at .7 power factor. Larger transformers with a regulation of 1 per cent. or better at a unity power factor load, would have about 3 per cent. regulation at .7 power factor.

Alternators also are rated in kva. output, usually at any value of power factor between unity and .8.

The deleterious effects of low power factor loads on alternators are even more marked than on transformers. These are, decreased kw. capacity, the necessity for increased exciter capacity, decreased efficiency, and impaired regulation.

Assume the case of a 100 kva. .6 power factor, 60 kw. output. It is probable that normal voltage could be obtained only with difficulty, unless the alternator was especially designed for low power factor service. The lagging power factor current in the armature sets up a flux which opposes the flux set up by the fields, and in consequence tends to demagnetize them, resulting in low armature voltage.

It is often impracticable, without the installation of new exciters, to raise the alternator voltage by a further increase of the exciting voltage and current. The field losses, and therefore the field heating of the alternator, when it is delivering rated voltage and current, are greater at lagging power factor than at unity. Increased energy input and decreased energy output both cause a reduction in efficiency.

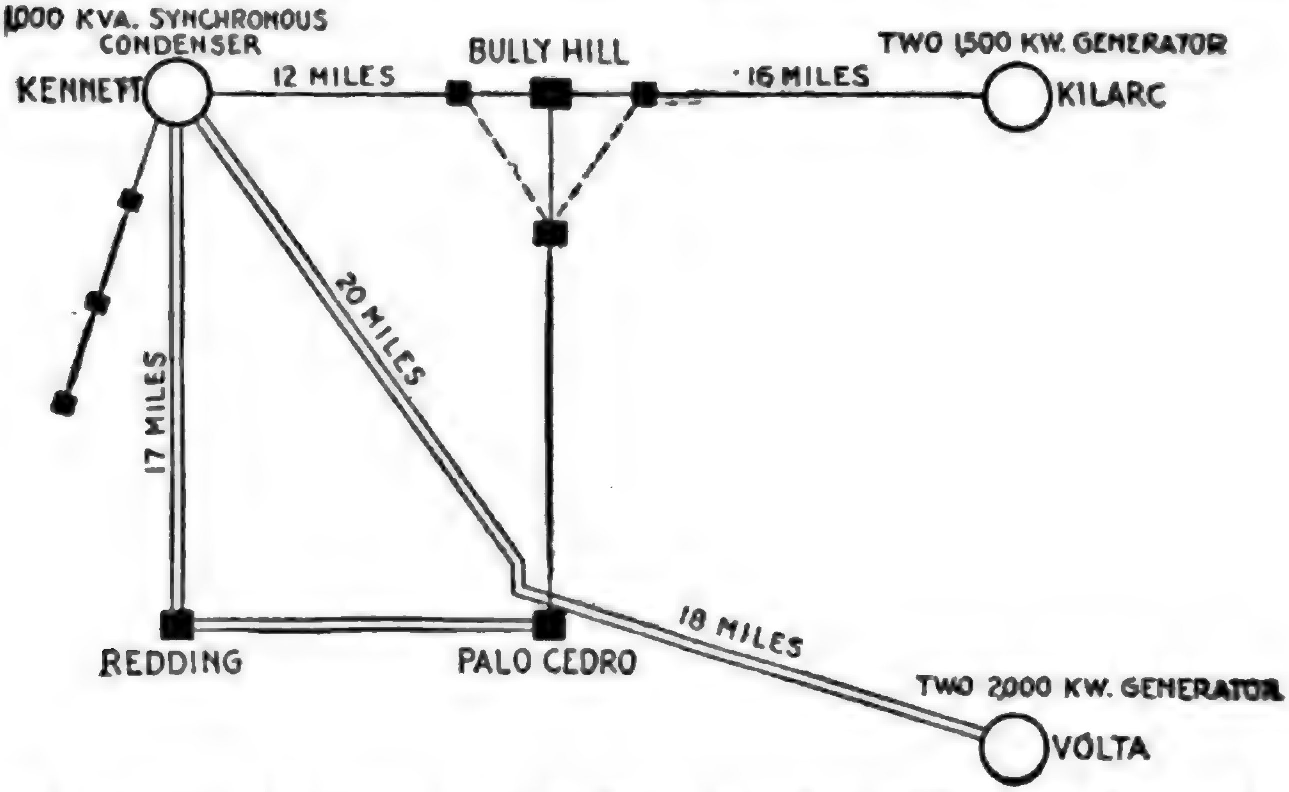
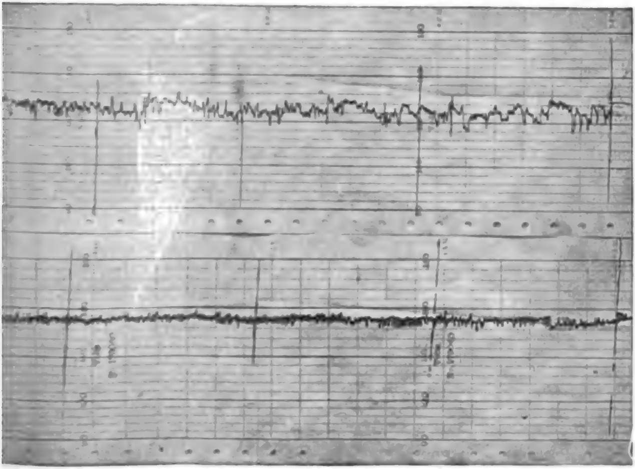


FIG. 2,482.—Diagram of a section of the Northern California Power Co.'s transmission system, showing relative location of alternators and synchronous condenser. The synchronous condenser is installed at Kennett, which is served by generating stations at Kilarc and Volta, located respectively 28 and 38 miles from the point at which the condenser is operated. The local demand amounts to about 6,500 kw., and before the installation of the synchronous condenser, the power factor was about 79 per cent. and after installing, about 96 per cent. while the voltage at the point where the synchronous condenser is installed is raised approximately 10 per cent. during the change from no load to full load. In order to obtain close voltage regulation, a regulator is used in connection with the synchronous condenser and holds the voltage, at the center of distribution, within 2 per cent. The regulator is mounted on the side of the control panel and connected in the field of the synchronous condenser to automatically change the excitation and compensate for voltage variations. A graphic demonstration of the improvement in voltage regulation, which has been secured in this case, is given by the curve drawing voltmeter records reproduced in fig. 2,483.

The regulation at unity power factor of modern alternators ıpable of carrying 25 per cent. overload, is usually about 8 per ent. Their regulation at .7 power factor lagging is about 25 er cent. The effect of low power factor on the lines can best be hown by the following example:

EXAMPLE.—Assuming a distance of five miles and a load of 1,000 kw. and desiring to deliver this load at a pressure of about 6,000 volts, three phase, with an energy loss of 10 per cent., each conductor at unity power factor would have to be 79,200 c.m., at .9 power factor, 97,533 c.m., and at .6 power factor, 218,000 c.m. In other words, at the lower power factor of .6, the investment in copper alone would be 2.8 times as much.



IG. 2,483.—Curve drawing voltmeter records at Kennett, Cal. The upper curve shows voltage regulation with synchronous condenser out of service, and the lower curve, with synchronous condenser in operation.

If the same size of wire were used at both unity and .6 power factor lagging, the energy loss would be about 2.8 times the loss at unity power factor, or about 28 per cent. Low lagging power factor on a system, therefore, will generally mean limited output of prime movers; greatly reduced kilowatt capacity of generator, transformer and line; and increased energy losses. The regulation of the entire system will also be poor.

Cost of Synchronous Condenser vs. Cost of Copper.—Referring to the example given in the preceding paragraph, and calculating the necessary extra investment in copper with the .6 power factor load, and copper at 17 cents per pound, the result is that 29,292 pounds more copper is required than with the power factor of .9 which means a total extra investment in copper alone of $5,000 (29,292 x $.17). A synchronous condenser of sufficient capacity to accomplish the same result would cost about the same amount. It would therefore cost less to install the condenser because at the same time a considerably increased capacity would be obtained from the alternators, transformers, etc.

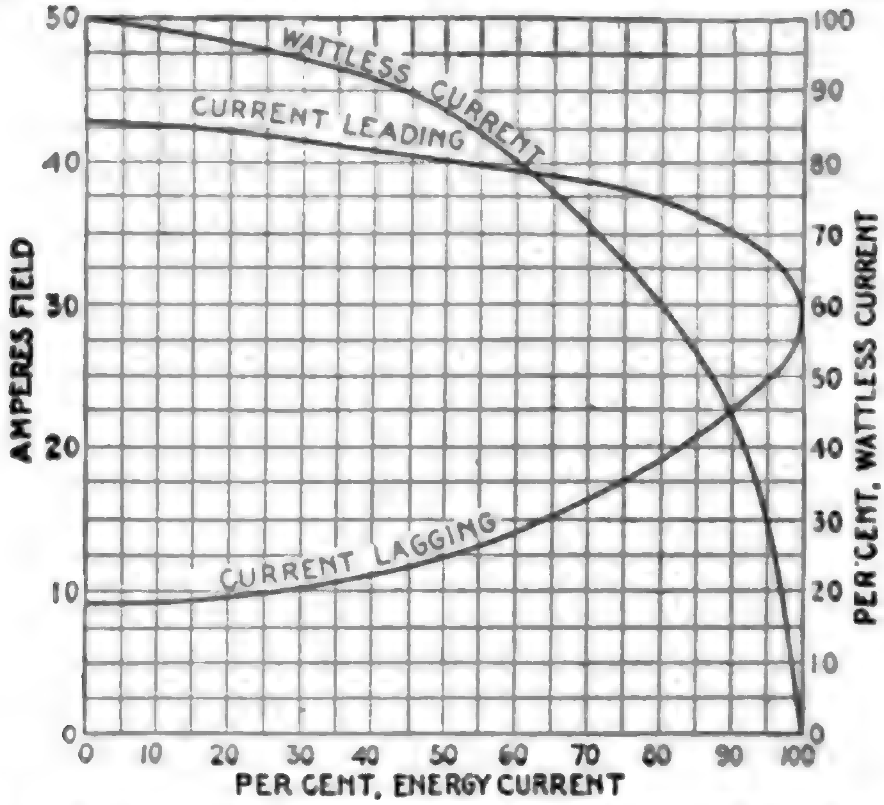


FIG. 2,484.—Diagram showing the **field current taken by a synchronous motor** of normal design when operating at normal kva. input at various power factors. **It will be noted that a slight departure from unity power factor necessitates a considerable change in field current.** As the field curves increase with the square of the current, there is a rapid increase in temperature with leading current. *This action of leading or lagging current serves automatically to keep the flux constant in the armature with changes in field excitation.* **When the motor is running at unity power factor,** an increase in field excitation causes a leading current to flow, and at the same time this leading current demagnetizes the field until the density of the armature is restored to its normal value. **If the field be decreased** a lagging current flows which in turn magnetizes the field bringing the density back to its original value. Therefore, with a constant line voltage, the iron losses in a synchronous motor are approximately constant irrespective of the field excitations with the exception that the internal voltage will vary slightly due to the armature I R drop, the density being a trifle lower at full load than at no load.

Synchronous Condenser Calculations.—In figuring on the installation of a condenser for correcting power factor troubles, a careful survey of the conditions should be made with a view of determining just what these troubles are and to what extent they can be remedied by the presence of a leading current in the system.

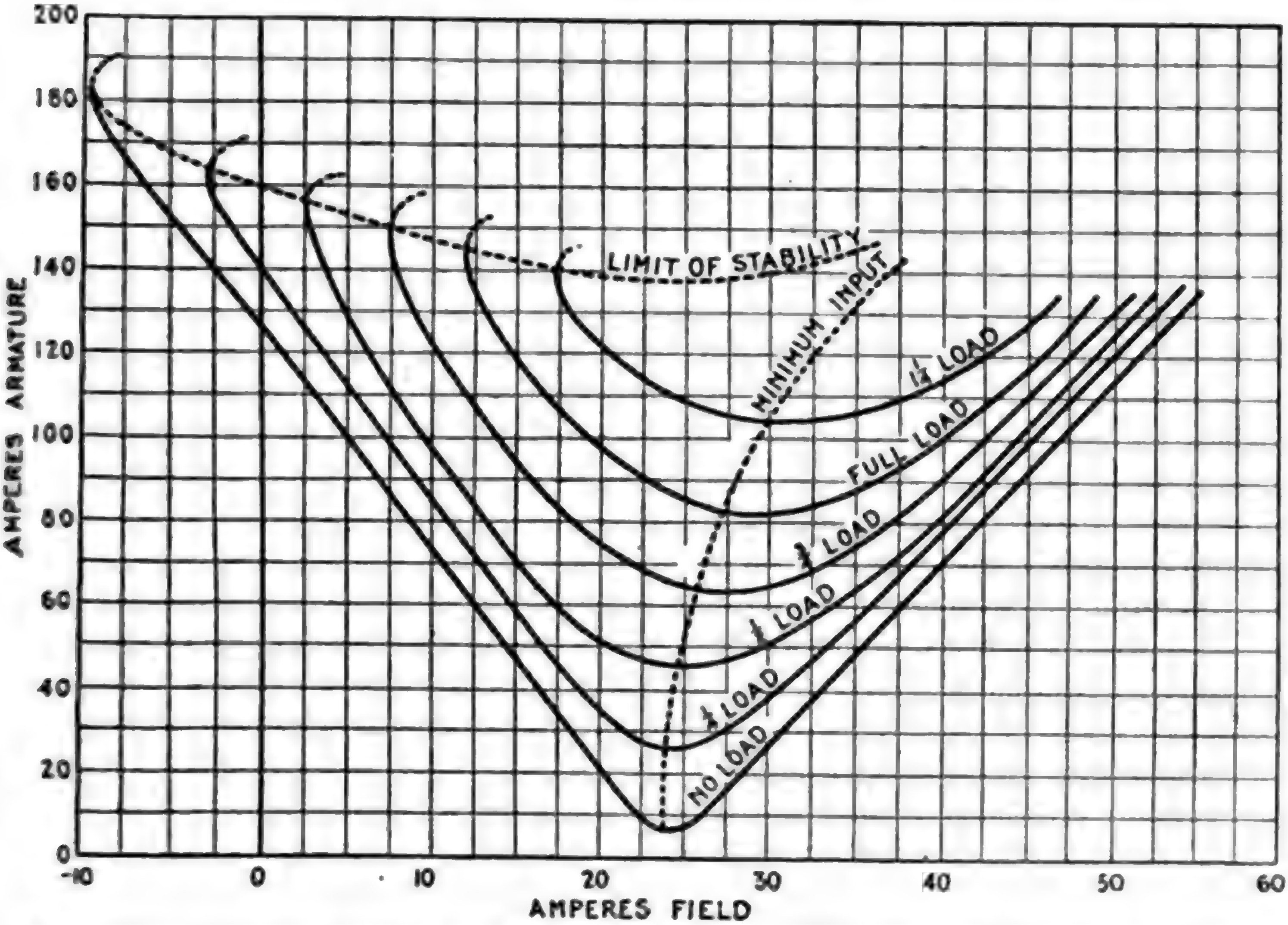


FIG. 2,485.—Diagram showing a set of **phase characteristic curves** taken **from** a General Electric **synchronous motor. These curves show** *the current input to the motor at various loads with constant voltage and varying field excitation.* There is a certain field current at each load that causes a minimum current. Any increase or decrease of field from the value increases the current and causes it to lead or lag with respect to the line voltage. By referring to the *minimum input* curve, it will be noted that if the machine be running at full load minimum input current and load is taken off, the current will be leading or vice versa. In each case the phase characteristic curve was run back on the lagging side to the break down point. **At no load** and one quarter load the motor still ran in step when the field was reduced to zero and even taken off altogether, and it was necessary to reverse the field current in order to back down the motor. **The motor runs without slip,** as a synchronous motor, in this condition, obtaining its excitation from the lagging current and running as a reaction machine. The amount of load a machine will carry without field varies with the design, the average being about 40% of full load. **It will be noted** from the *limit of stability* curve that the lighter the load on the machine when it breaks down from lack of sufficient excitation, the greater the current input at this point. **The no load characteristic** rises sharply on each side with slight change in field current, while it flattens out with increase in load until at overload the current input is practically the same throughout a large range of field cu

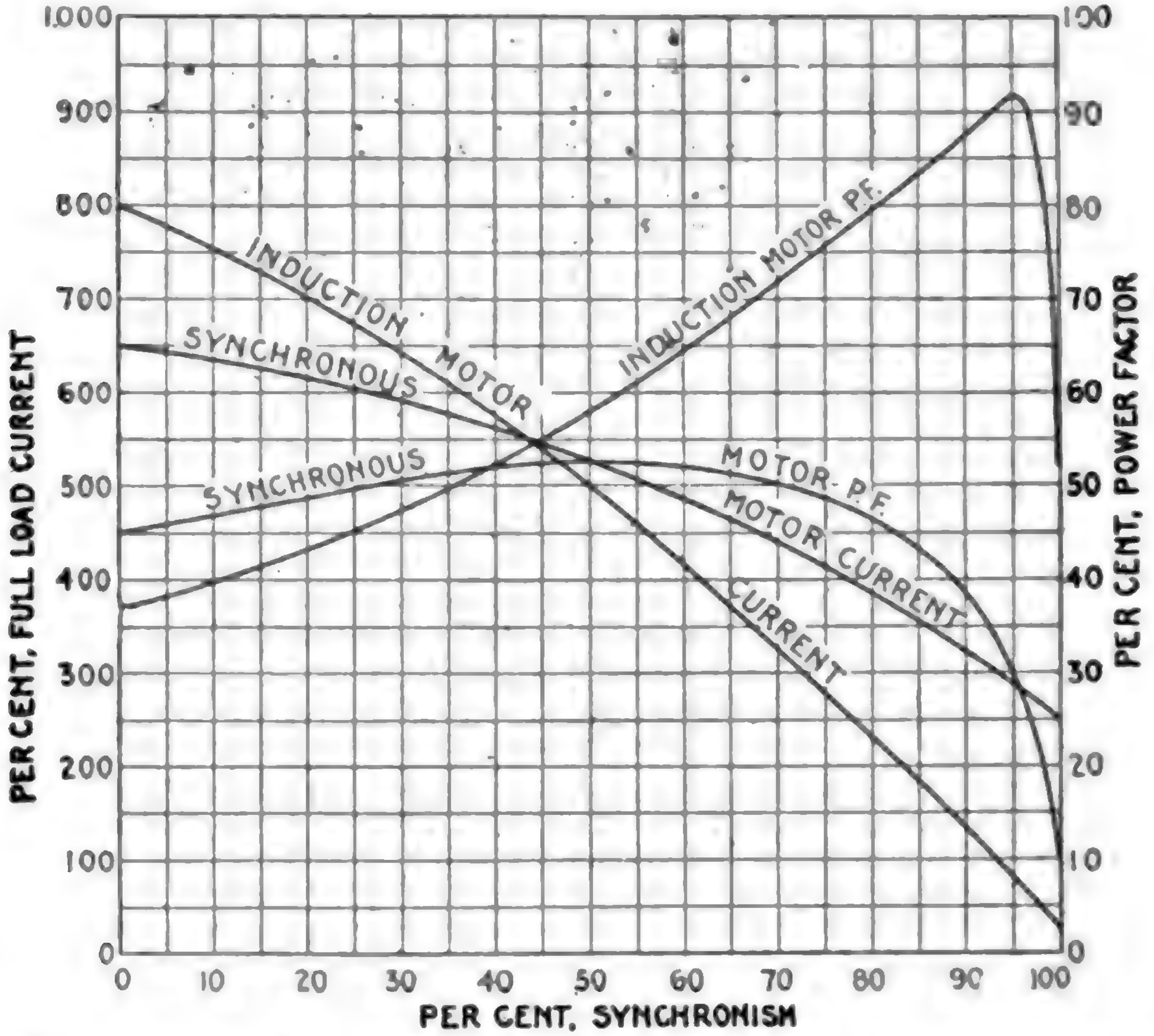


FIG. 2,486.—Comparison of the **speed current curves** and **speed power factor curves** of a typical synchronous, and induction motor. It will be noted that the power factor of the synchronous motor at start is higher than that of the induction motor owing to the higher resistance of the squirrel cage winding. **As the machine approaches synchronism,** however, the magnetizing current of the induction motor drops to a very much lower value than in the synchronous motor and the power factor is consequently much higher. The magnetizing current of the induction motor at full speed is usually 25 per cent. of full load current while that of the synchronous motor is from 200 to 250 per cent. of full current, or even higher when running full speed and normal voltage. This of course is due to the large air gap on the synchronous machine. **The current at start** with full voltage applied is usually higher in an induction motor owing to the fact that the total impedance of the stator and rotor are less due to the greater distribution of the windings and the lower resistance of the squirrel cage. **The high magnetizing current** of a synchronous motor should not be lost sight of as it is a very important consideration in starting the machine. Even though the motor can be brought practically to synchronous speed while still on the compensator, if line voltage be thrown on, there will be a very heavy rush of current. The obvious thing to do is to get the field on the motor while still on the compensator, whenever possible, to avoid the high magnetizing current. This magnetizing current is obviously equal to the circuit current of the machine at no load field. In some cases additional torque near synchronism can be obtained by short circuiting the field winding through the field rheostat. This has the effect of reducing the resistance of the rotor winding to some extent and causing the motor to have less slip with a given load. The gain from this source is small, however, in most cases, as the self-inductance of the field winding is so high as to allow very little current to flow even if the field be short circuited so that the total effective resistance of the rotor winding is not materially reduced. In some cases where the torque is nearly sufficient, however, enough gain may be obtained to take care of the conditions. **If the field be short circuited** before the motor is started there will be a reduction in starting torque and an increase in current from the line, hence if this method be resorted to, arrangements must be made to short circuit the field after the motor has come to constant speed.

It is necessary to possess a thorough knowledge of the system, covering the generating capacity in energy and kva., average and maximum load, and power factor on the alternators, average and maximum load, and power factor on the feeders, system of distribution, etc.

The desirable location of a condenser is, of course, nearest the inductive load in order to avoid the transmission of the wattless current, but it often happens that a system is so interconnected that one large condenser cannot economically meet the conditions, in which case it may be better to install two or more smaller ones.

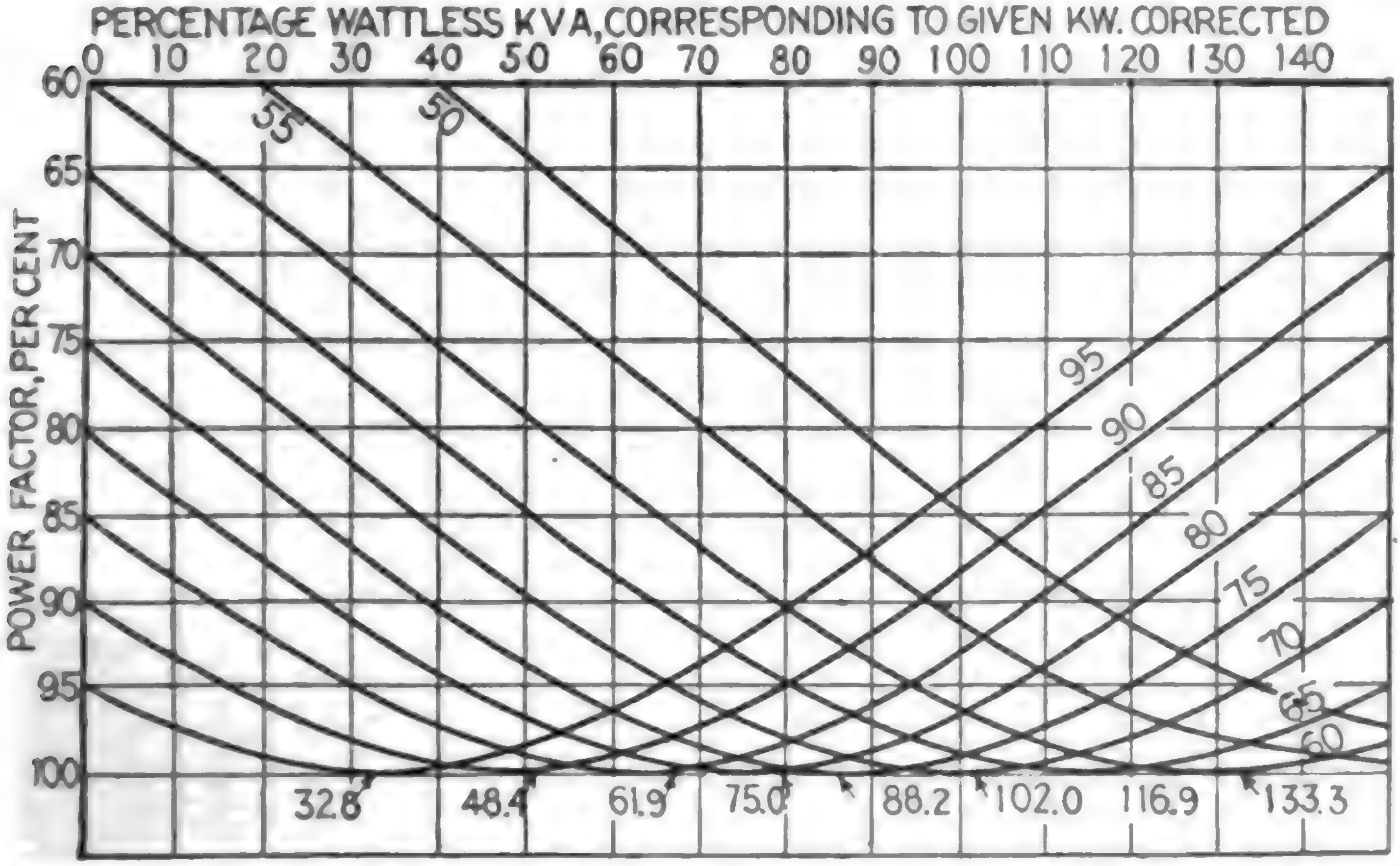


FIG. 2,487.—Curves showing amount of wattless component required to raise the power factor of a given kw. load to required higher value. The wattless components are expressed as percentages of the original kw. load. **The numbers at the right** which indicate the points of tangency of the power factor curves to the 100 per cent. line, show the amount of wattless component required to raise a given kw. load of given lagging power factor to unity power factor. Obviously the addition of further wattless component in a given case would result in a leading power factor less than unity.

The question of suitable attendance should also be considered and. for this reason, it may be necessary to compromise on the location. When the location of the condenser has been deci upon and the load and power factor within its zone determined, the proper size of condenser to raise the power factor to a given value can be found as follows:

The method of procedure can best be explained by reference to a concrete case. Assume a load of 450 kw. at .65 power factor. It is desired to raise the power factor to .9. What will be the rating of the condenser?

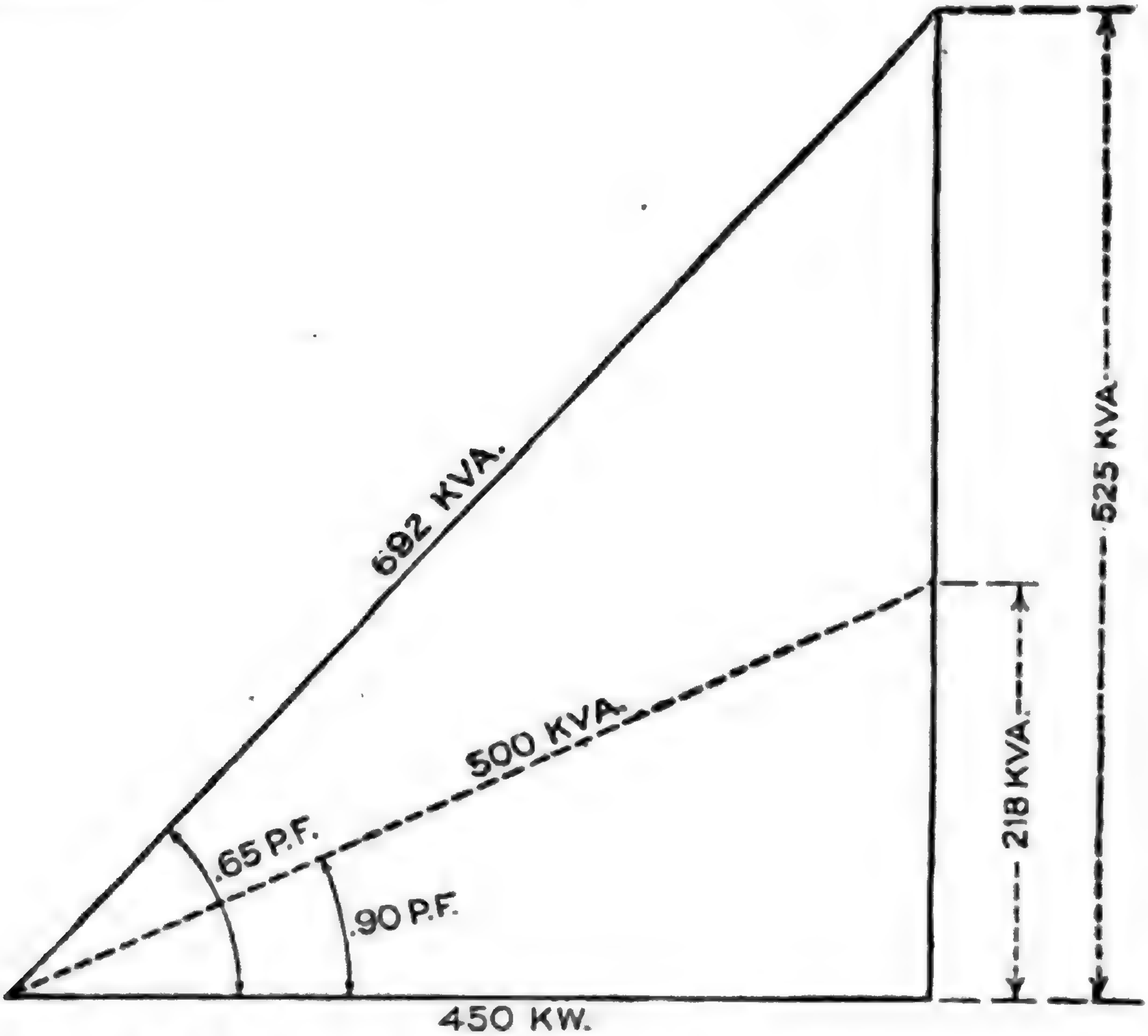


FIG. 2,488.—Diagram for synchronous condenser calculations.

Referring to the diagram, fig. 2,488, it is necessary to start with 450 kw. At .65 power factor, or 692 kva., this has a wattless lagging component of $\sqrt{692^2-450^2}=525$ kva. With the load unchanged and the power factor raised to .9, there will be 500 apparent kva., which will have a wattless component of $\sqrt{500^2+450^2}=218$ kva.

It is obvious that the condenser must supply the difference between 525 kva. and 218 kva., or 307 kva. A 300 kva. condenser would, therefore, meet the requirements.

If it be desired to drive some energy load with the condenser and still bring the total power factor to .9, proceed as indicated in fig. 2,489.

Assume a total load of 150 kw. on the motor. As before, 450 kw. at .65 power factor, or 692 kva., with a wattless component of 525 kva.

The energy load will be increased from 450 to 600 kw. as indicated, and with the power factor raised to .9 there will be a kva. of 667 with a wattless component of $\sqrt{667^2+600^2}=291$.

There must be supplied 525 − 291 = 234 in leading kva.

The synchronous motor then must supply 150 kw. energy and 234 kva. wattless, which would give it a rating of $\sqrt{150^2+234^2}=278$ kva. at .68 power factor.

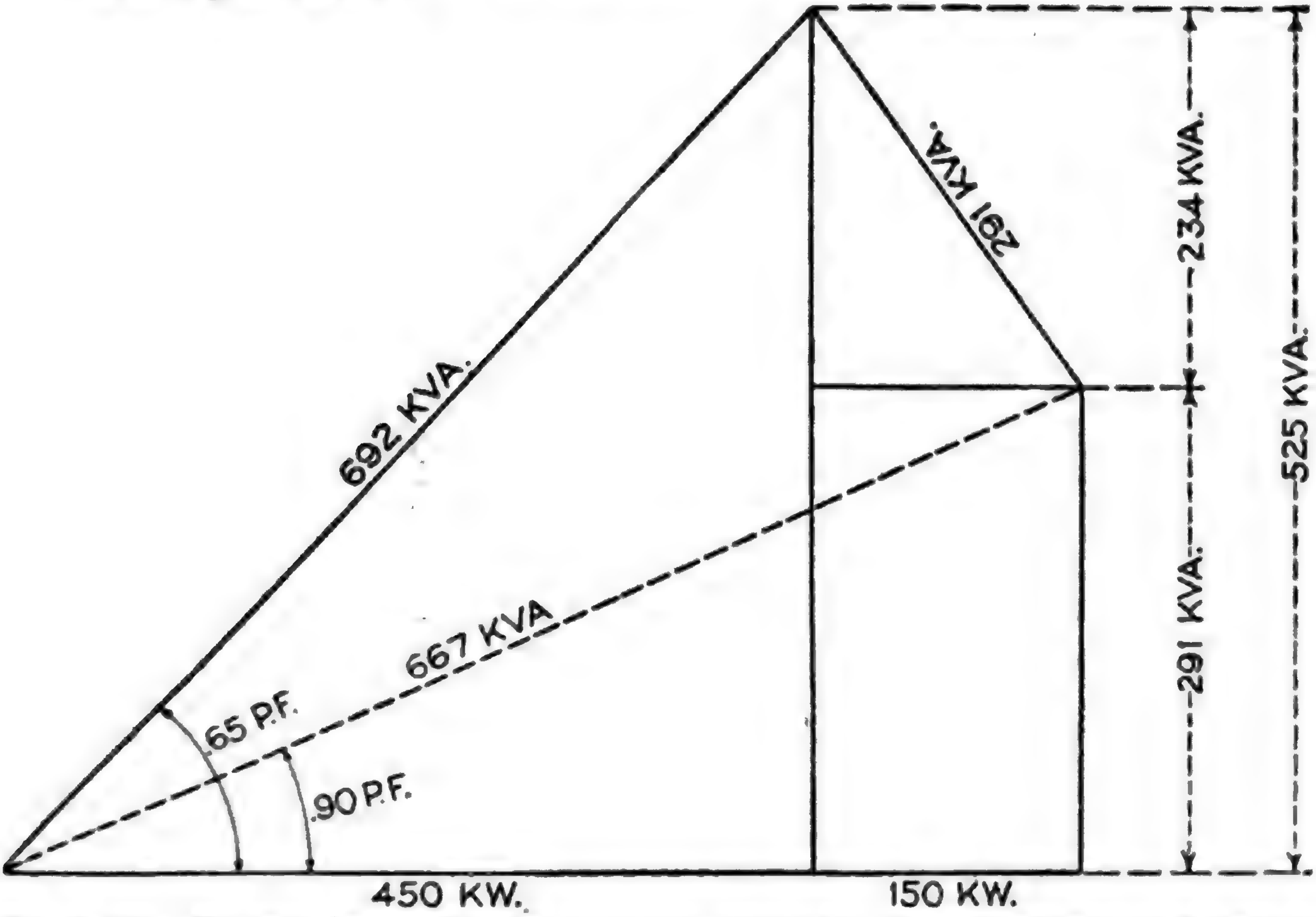


FIG. 2,489.—Diagram for synchronous condenser calculation for cases where it is desired to drive some energy load with the condenser and still bring the total power factor to .9.

The standard 300 kva. condenser would evidently raise the power factor slightly above .9 power factor leading.

By reference to the chart, fig. 2,490, the size of the required condenser can be obtained direct without the use of the above calculation. The method of using this curve is as follows: Assume a load of say 3,000 kw. at .7 power factor and that it be desired to raise the power factor to .9. Run up the vertical line at 3,000 kw. to the .7 power factor line, and from there along the horizontal line to the margin and find a wattless component at this power factor of 3,000 kva., approximately. Again run up the 3,000 kw. vertical line to the .9 power factor line and from there along the horizontal line to the margin and find a wattless component of 1,500 kva. The rating of the condenser will then be 3,000 kva. — 1,500 kva. = 1,500 kva. This table of course can be used for hundreds of kilowatts as well.

For determining the rating of a synchronous motor to drive an energy load this curve is not so valuable, although it can be used in determining the wattless component direct in all cases where the energy component

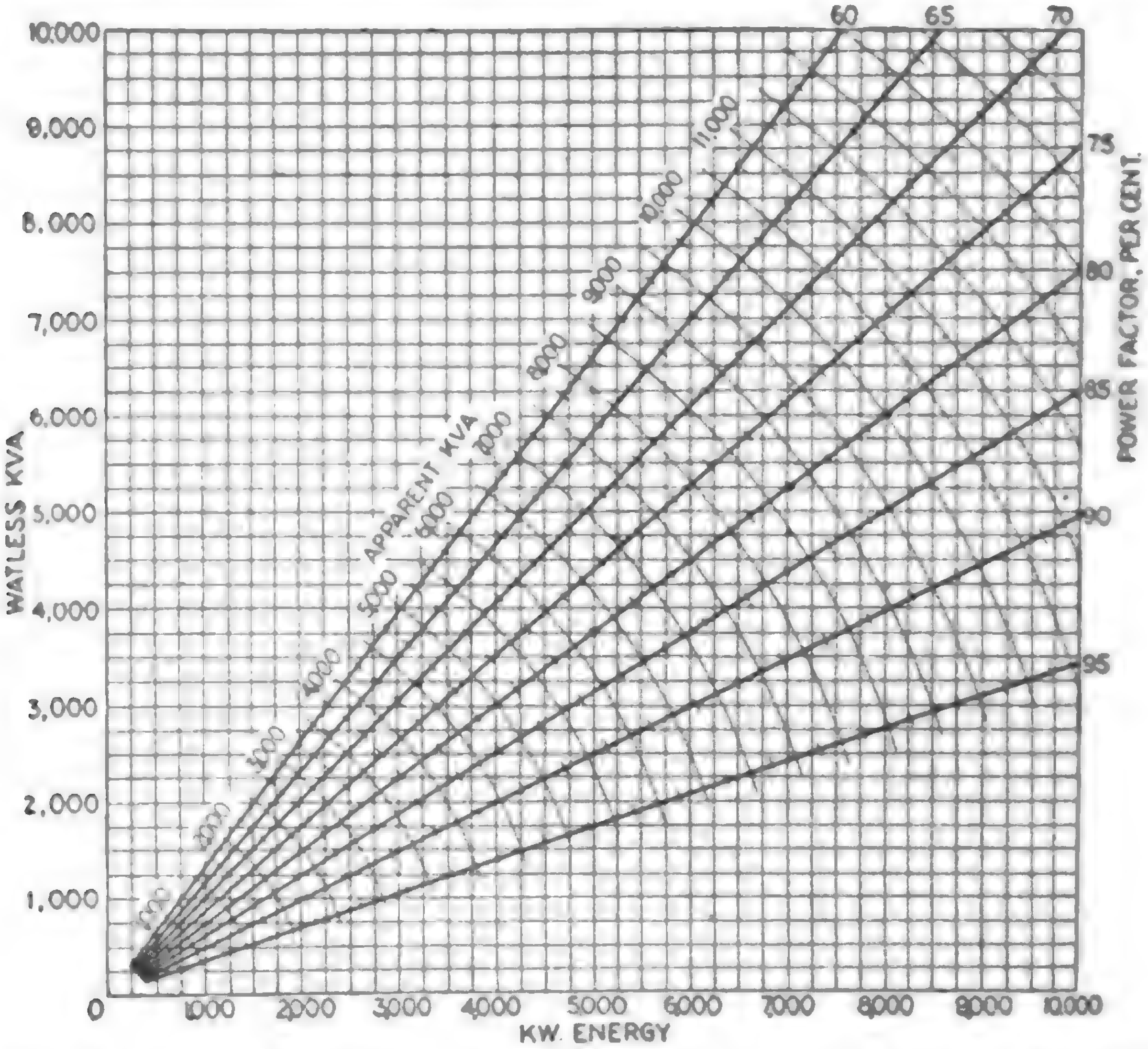


Fig. 2,490.—Curve showing the relation of energy load to apparent load and wattless components at different power factors.

and power factor are known. Knowing this energy component and power factor or wattless component, the energy load can obviously be found by referring to the curved lines on the diagrams, the curve that crosses the junction of the vertical energy line and the power factor or wattless component line giving the total apparent kva.

CHAPTER LXII

INDICATING DEVICES

Alternating current ammeters or voltmeters indicate the *virtual* values of the current or pressure respectively, that is to say, they indicate, *the square root of the mean square of a variable quantity.*

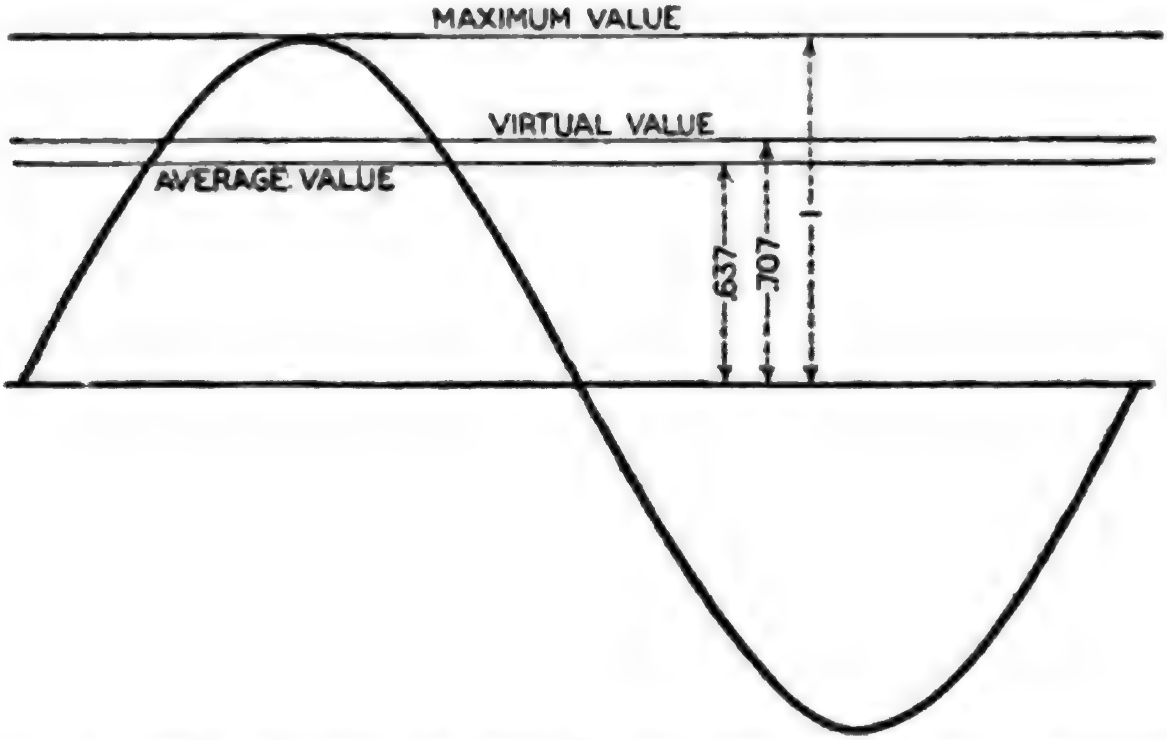


FIG. 2,491.—Line curve of alternating current, illustrating various current or pressure values. The virtual value, or .707 × maximum value, is the value indicated by an ammeter or voltmeter. Thus, if the maximum value of the current be 100 volts, the virtual value as indicated by an ammeter is 100 ×.707 = 70.7 amperes.

The virtual value of an alternating current or pressure *is equivalent to that of a direct current or pressure which would produce the same effect.*

For instance an alternating current of 10 virtual amperes will produce the same heating effect as 10 amperes direct current.

The relation of the virtual value of an alternating current to the other values is shown in fig. 2,491. When the current follows the sine law, the square root of the mean square, value of the sine functions is obtained by multiplying their maximum value by $1 \div \sqrt{2}$, or .707.

The word **effective** is commonly used *erroneously* for **virtual**, even among the best writers and the practice cannot be too strongly condemned[*].[†] The difference between the two is illustrated in Guide No. 5, page 1,013, fig. 1,237, the mechanical analogy here given may make the distinction more marked.

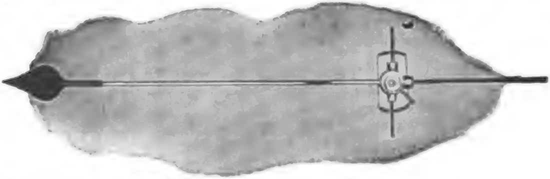


FIG. 2,492.—Wagner tubular aluminum pointer.

In the operation of a steam engine, there are two pressures acting o the piston:

1. The *forward* pressure;
2. The *back* pressure.

The forward pressure on one side of the piston is that due to the liv steam from the boiler, and the back pressure, on the other side, that du to the resistance or opposition encountered by the steam as it exhaust from the cylinder.

In order that the engine may run and do external work, it is evide that the forward pressure must be greater than the back pressure, an it follows that the pressure available to run the engine is the difference between these two pressures, *this pressure difference being known as the* **effective pressure,** that is to say

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[*] NOTE.—I adhere to the term virtual, as it was in use before the term efficace whi was recommended in 1889 by the Paris Congress to denote the *square root of mean square val* The corresponding English adjective is *efficacious*, but some engineers mistranslate it w the word *effective*. I adhere to the term virtual mainly because effective is required in usual meaning in kinematics to represent the resolved part of a force which acts obliquely the line of motion, the effective force being the whole force multiplied by the cosine of t angle at which it acts with respect to the direction of motion.—*S. P. Thompson.*

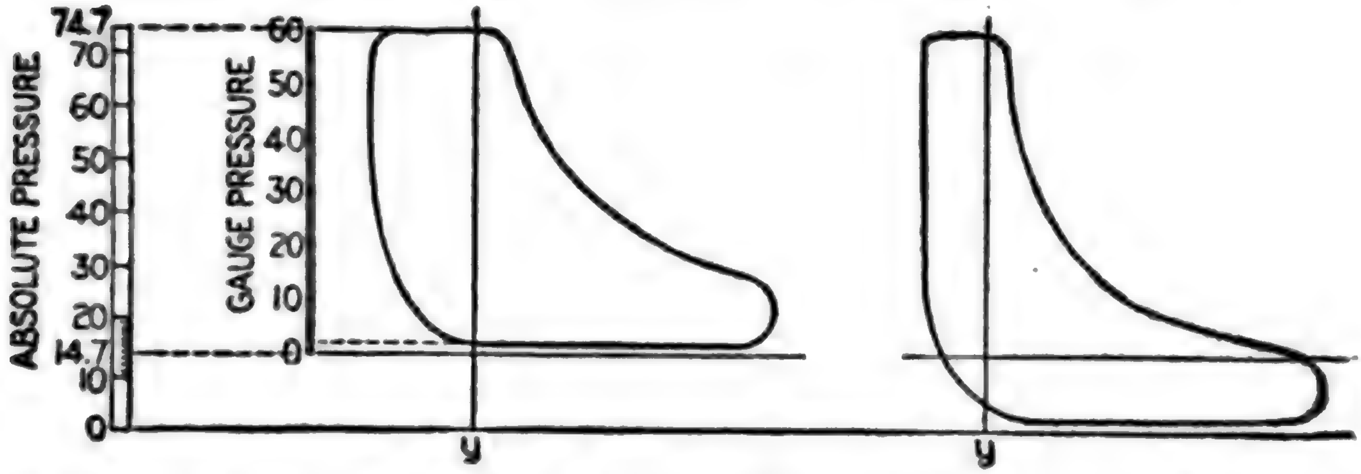
[†] NOTE.—The author adheres to the term *virtual* because in mechanics the adjecti *effective* is used to denote the difference of two opposing forces; for instance, at any insta in the operation of a steam engine, *effective pressure = forward pressure—back pressure*, henc to be consistent in nomenclature, the term effective cannot be used for the forward or virtu pressure, that is, the pressure impressed on an electric circuit.

effective pressure = forward pressure − back pressure

Thus, electrically speaking, the effective voltage is that voltage which is available for driving electricity around the circuit, that is,

effective volts = virtual volts − back volts
= virtual pressure − (virtual pressure − drop)

In the case of the steam engine, the forward pressure absolute, that is, measured from a perfect vacuum is the virtual pressure (not considering the source). The back pressure may vary widely for different conditions of operation as illustrated in figs. 2,493 and 2,494.



IGS. 2,493 and 2,494.—Steam engine **indicator cards** *illustrating in mechanical analogy,* **the misuse of the term effective** as applied to the pressure of an alternating current. The card fig. 2,493, represents the performance of a steam engine taking steam at 60 lbs. (gauge) pressure and exhausting into the atmosphere. The exhaust line being above the atmospheric line shows that the friction encountered by the steam in flowing through the exhaust pipe produces a back pressure of two lbs. Hence at the instant represented by the ordinate *y*, the **effective pressure** is 60 − 2 = 58 lbs., or using **absolute pressures,** 74.7 − 16.7 = 58 lbs., the **virtual pressure** being 60 lbs. gauge, or 74.7 lbs. absolute. Now, the **back pressure** may be considerably reduced by exhausting into a condenser as represented by the card, fig. 2,494. Here, most of the pressure of the atmosphere is removed from the exhaust, and at the instant *y*, the back pressure is only 6 lbs., and the effective pressure 74.7 − 6 = 68.7 lbs. Thus, in the two cases **for the same virtual pressure** of 60 lbs. gauge or 74.7 lbs. absolute, **the effective pressures are** 58 lbs. and 68.7 lbs. respectively.

In the measurement of alternating current, it is not the aver-ge, or maximum value of the current wave that defines the urrent commercially, but the *square root of the mean square* alue, because this gives the equivalent heating effect referred o direct current. There are several types of instrument for easuring alternating current, and they may be classified as

1. Electromagnetic (moving iron);
2. Hot wire;
3. Induction;
4. Dynamometer.

Electromagnetic or Moving Iron Instruments.—This type of instrument depends for its action upon the pull of flux in endeavoring to reduce the reluctance of its path. This pul is proportional to the product of the flux and the current, an so long as no part of the magnetic circuit becomes saturated the flux is proportional to the current, hence the pull is proportional to the square of the current to be measured.

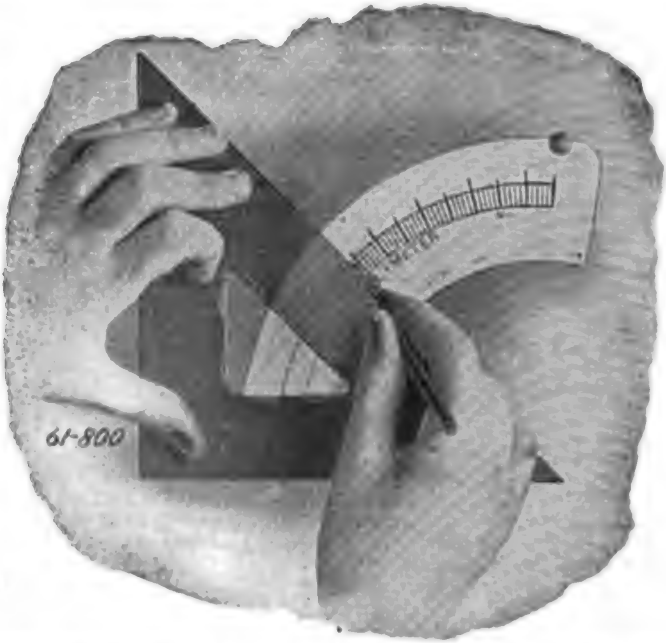
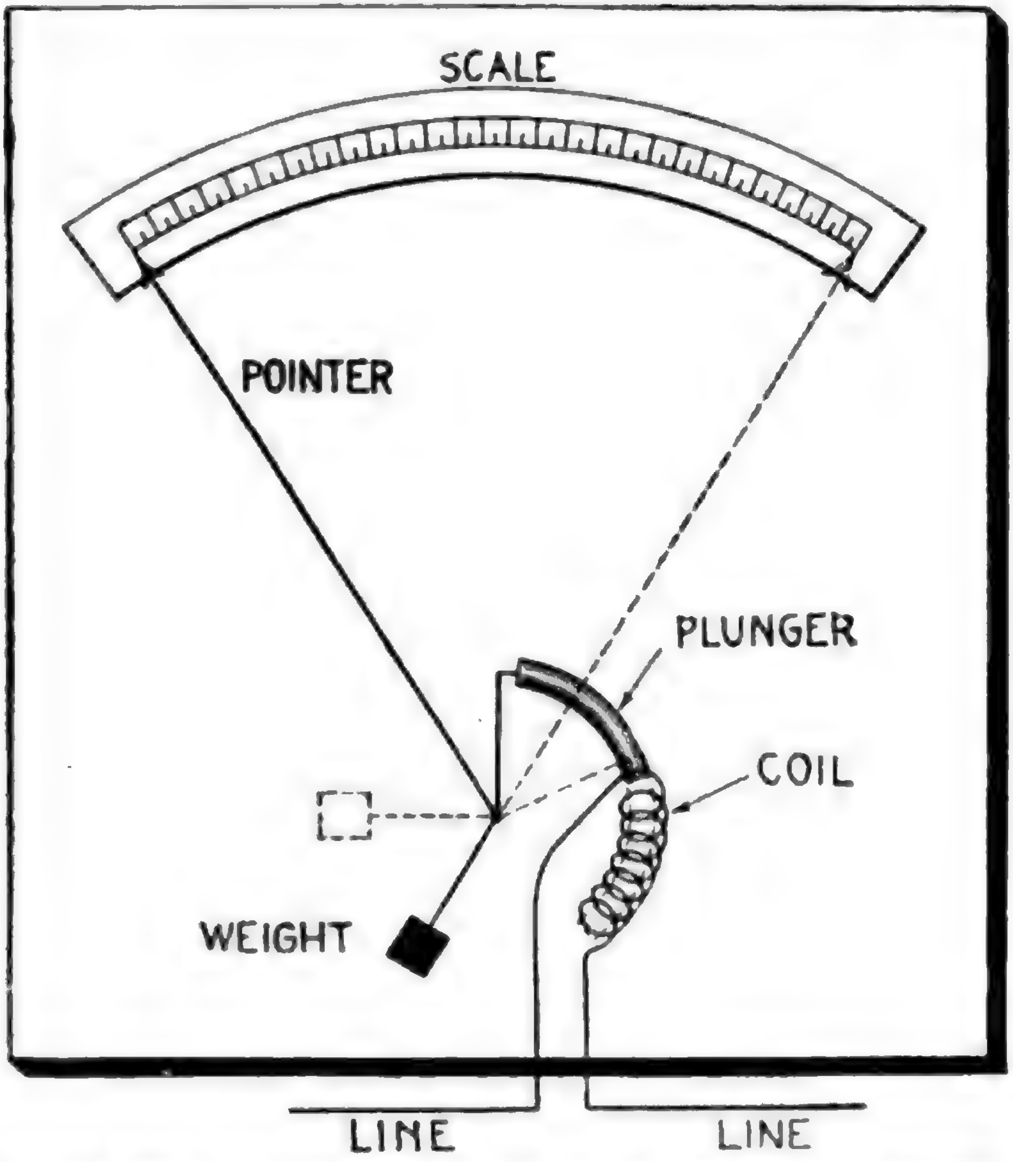


FIG. 2,495.—A **calibrated** scale. This means that printed scales are not employed, but eac instrument has its scale divisions plotted by actual comparison with standards, after whic the division lines are inked in by a draughtsman. There are makes of direct curre instruments employing printed scales in which the scale deflections are fairly accurat even though the scales are printed, but printed scales should not be used on alternatin current instruments.

Ques. What are some objections to moving iron instruments?

Ans. Instruments of this type are not independent of the frequency, wave form, or temperature and external magnetic fields may affect the readings temporarily.



ɪɢ. 2,497.—Plunger form of electromagnetic or moving iron type of ammeter.

There are several forms of moving iron ammeters, which may e classified as

1. Plunger;
2. Inclined coil;
3. Magnetic vane.

Ques. Describe the plunger type.

Ans. This type of ammeter consists of a series coil and a soft iron plunger forming a solenoid, the plunger is so suspended that the magnetic pull due to the current flowing through the coil is balanced by gravity, as shown in fig. 2,497.

Ques. How should the plunger be constructed to adapt it to alternating current, and why?

Ans. It should be laminated to avoid eddy currents.

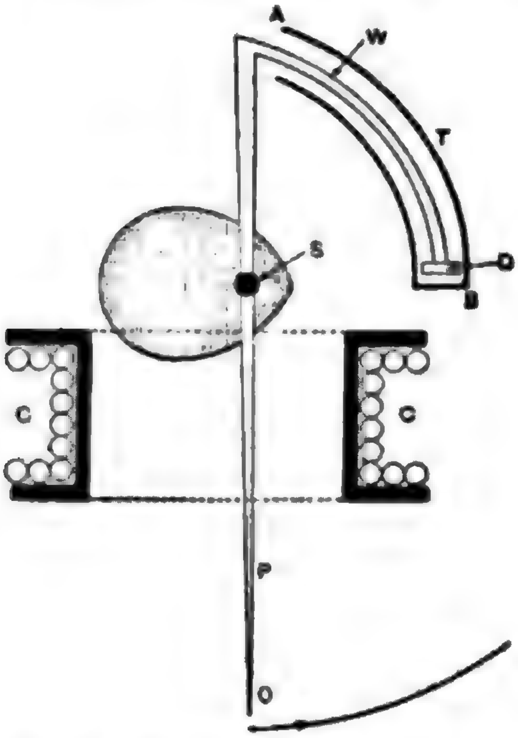


FIG. 2,497.—One form of **plunger instrument** as made by Siemens. *It has gravity con is dead beat, and is shielded from external magnetic influence.* **The moving system co sists of** a thin soft iron pear shaped plate I pivoted on a horizontal spindle S running jewelled centers. To this spindle S is also attached a light pointer P and a light w W, bent as shown, and carrying a light piston D, which works in a curved air tube This tube T is closed at the end B but fully open at the other A, and constitutes air damping device for making the instrument dead beat.

Ques. What is the character of the scale and how should it be constructed?

Ans. The scale is not uniform and should be hand mad and calibrated under the conditions which it is to be used.

Ques. What is the objection to moving iron ammeters

Ans. Since the coil carries the entire current they are larg and expensive.

Ques. What precaution should be taken in installing moving iron ammeters?

Ans. Since gravity is the controlling force, the instrument should be carefully levelled.

Ques. Describe an inclined coil instrument.

Ans. It consists of a coil mounted at an angle to a shaft carrying the vane and pointer, as shown in fig. 2,498. A spring forms the controlling force and holds the pointer at zero when no current is flowing.

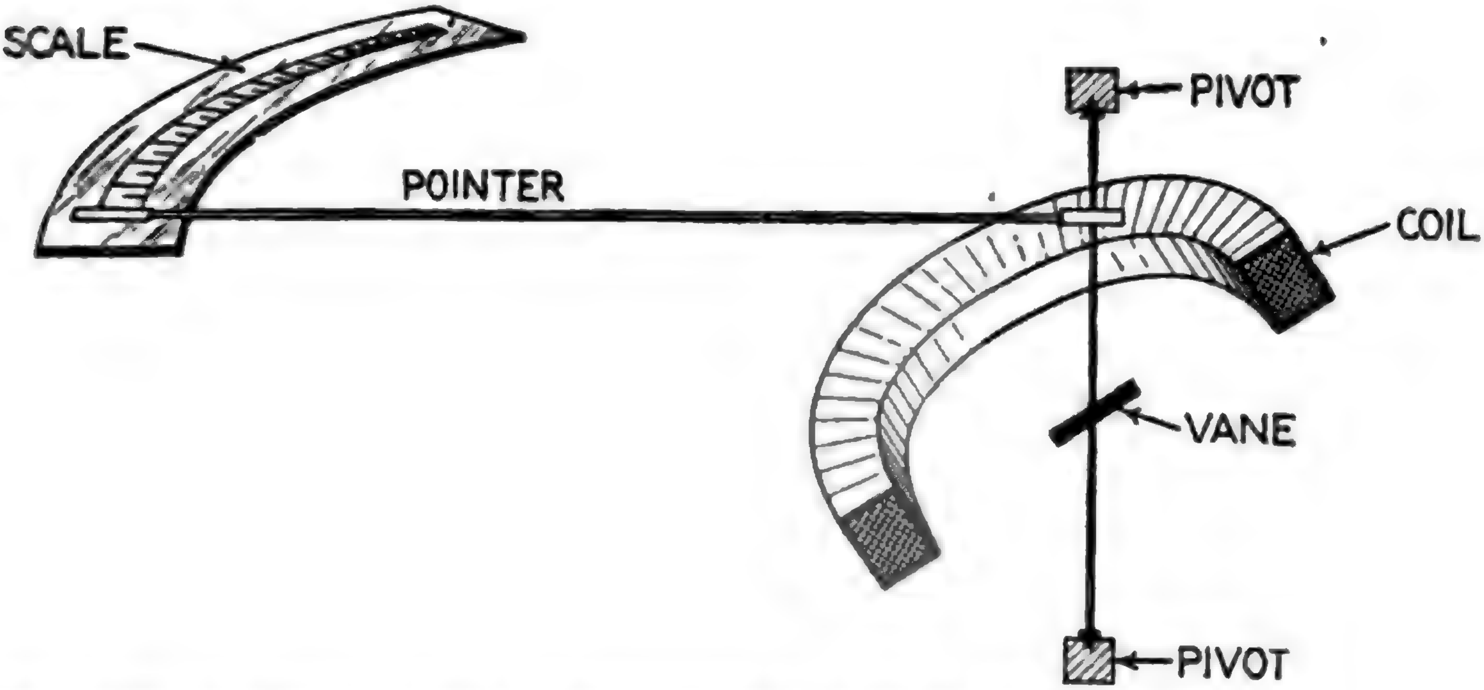


Fig. 2,498.—Inclined coil form of electromagnetic or moving iron instrument.

Ques. What is the principle of operation of the inclined coil instrument?

Ans. When a current is passed through the coil, the iron tends to take up a position with its longest sides parallel to the lines of force, which results in the shaft being rotated and the pointer moved on the dial, the amount of movement depending upon the strength of the current in the coil.

Ques. Describe a magnetic vane instrument.

Ans. It consists of a small piece of soft iron or *vane* mounted

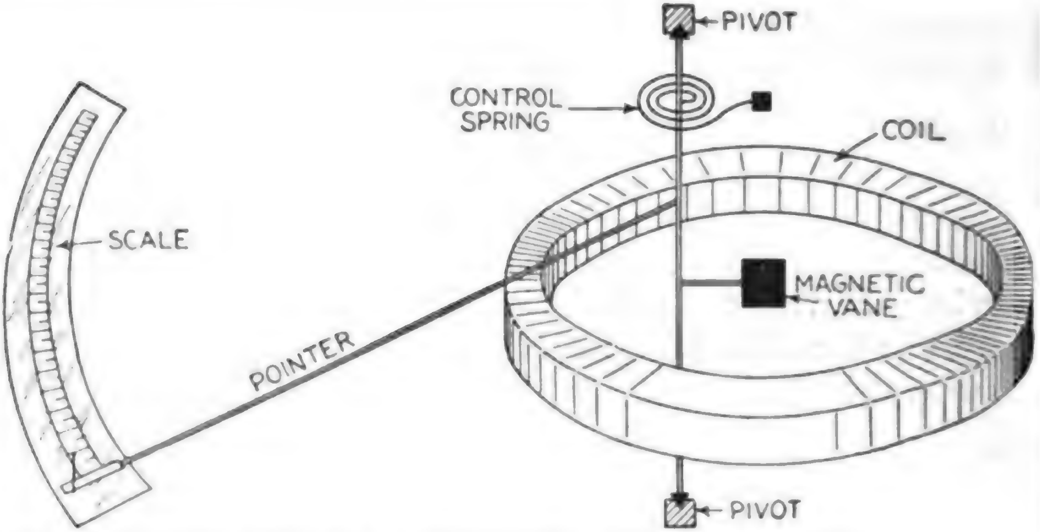

PIVOT
CONTROL SPRING
COIL
SCALE
MAGNETIC VANE
POINTER
PIVOT

FIG. 2,499.—Magnetic vane form of electromagnetic or moving iron instrument.

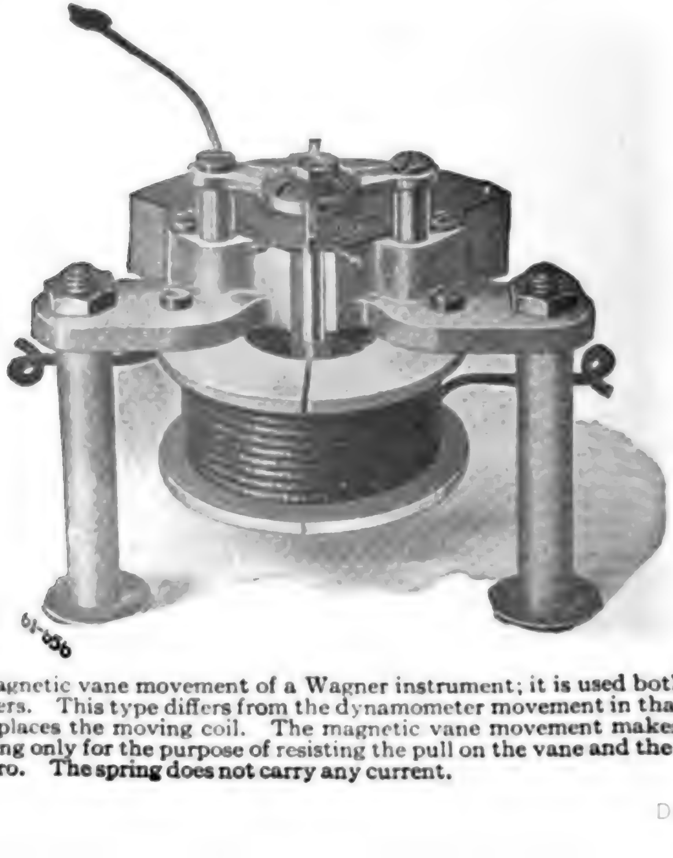


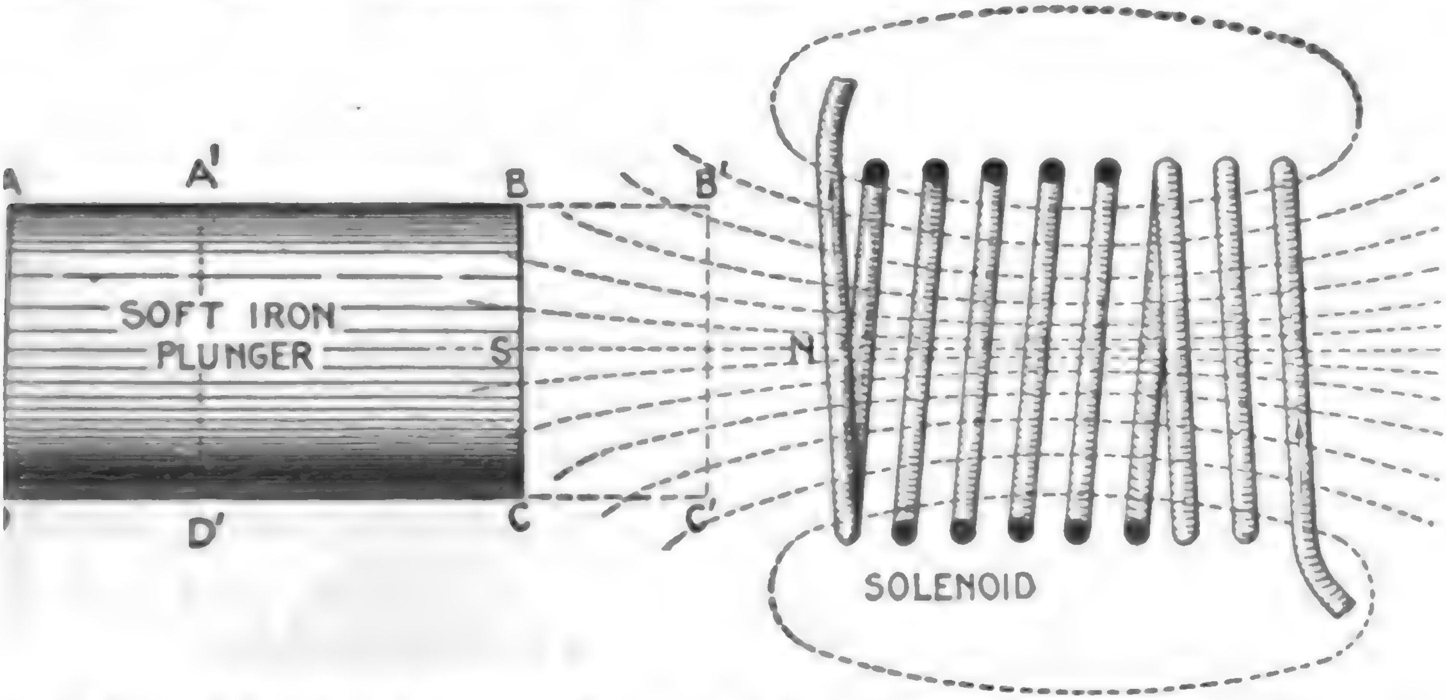
FIG. 2,500.—Magnetic vane movement of a Wagner instrument; it is used both for voltmeters and ammeters. This type differs from the dynamometer movement in that a vane of very soft iron replaces the moving coil. The magnetic vane movement makes use of its controlling spring only for the purpose of resisting the pull on the vane and the returning of the needle to zero. The spring does not carry any current.

on a shaft that is pivoted a little off the center of a coil as shown in fig. 2,499, and carrying a pointer which moves over a scale.

Ques. How does it work?

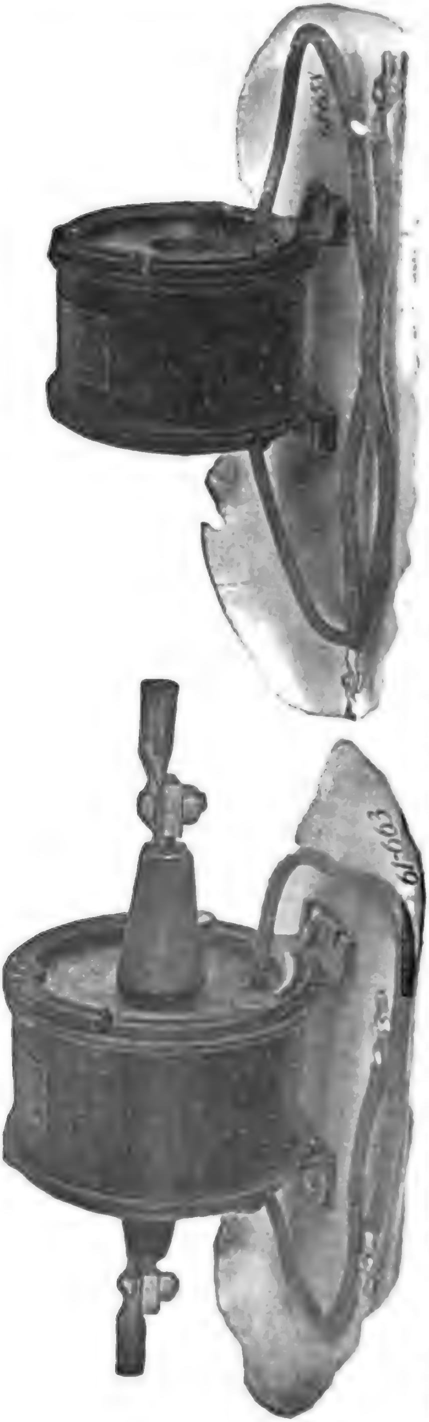
Ans. Its principle of operation is that *a piece of soft iron placed in a magnetic field and free to move, will move into such position as to conduct the maximum number of lines of force.*

The current to be measured is passed around the coil, producing a magnetic field through the center of the coil. The magnetic field inside the coil is strongest near the inner edge, hence, the vane will move against the restraining force of a spring so that the distance between it and the inner edge of the coil will be as small as possible.



IG. 2,501.—**Solenoid and plunger illustrating the operation** *of moving iron instruments.* When a current flows through the coil, a field is set up as indicated by the dotted lines of force. The current flowing in the direction indicated by the arrow induces a north pole at N, which in turn induces a south pole in the plunger at S, thus attracting the plunger. **The effect of the field upon the plunger** may also be stated by saying that *it tends to cause the plunger to move in a direction so as to conduct the maximum number of lines of force,* that is, *toward the solenoid.* Thus if ABCD be the initial position of the plunger only five lines of force pass through it: should it move to the position A′ B′ C′ D′, the number of lines passing through it will then be 9, assuming the field to remain unchanged.

The operation of moving iron instruments of the plunger type may be explained by saying that the current flowing in the coil produces a pole at its end and induces an unlike pole at the end of the plunger nearest the coil, thus attracting the plunger, as illustrated in fig, 2,501 abov



FIGS. 2,502 and 2,503.—Wagner series transformers. **Fig. 2,502. wound primary series transformer; fig. 2,503. open primary transformer.** Wagner series transformers are made in three general types: One for switchboard mounting with wound primary; one for switchboard mounting with open primary, and one with open primary suitable for slipping over bus bars or switch stud. These transformers have 5 ampere secondary winding, and are intended for use in connection with instrument of scale capacity 0–5, although the scale should be calibrated to indicate the primary current. The capacities are from 2 watts to 50 watts, being suitable for operation on circuits of 730 to 66,000 volts.

Hot Wire Instruments.—Instruments of this clas depend for their operatio on the expansion and contraction of a fine wire carrying either the current t be measured or a definite proportion of that current.

The expansion or contraction of the wire is caused by temperature changes which in turn are due to the heating effect of the current flowing through the wire.

Since the variations in the length of the wire are extremely small, considerable magnification is necessary. Pulleys or levers are sometimes used to multiply the motion, and sometimes the double sag arrangement shown in fig. 2,504.

As here shown, A is th active wire carrying the current to be measured an stretched between the terminals T and T′. It is pulle taut at its middle point b another wire C, which carries no current, and is in its turn, kept tig by a thread passing roun the pulley D attached t the pointer spindle, the whole system being kept in tension by the spring E.

Hot wire instruments are equally accurate with alternating or direct current, but have cramped scales (since the deflection is proportional to the square of the current), and are liable to creep owing to unequal expansion of the parts. There is also the danger that they may be burnt out with even comparatively small overloads. They are not affected by magnetic fields but consume more current than the other types, these readings are inaccurate near either end of the scale.

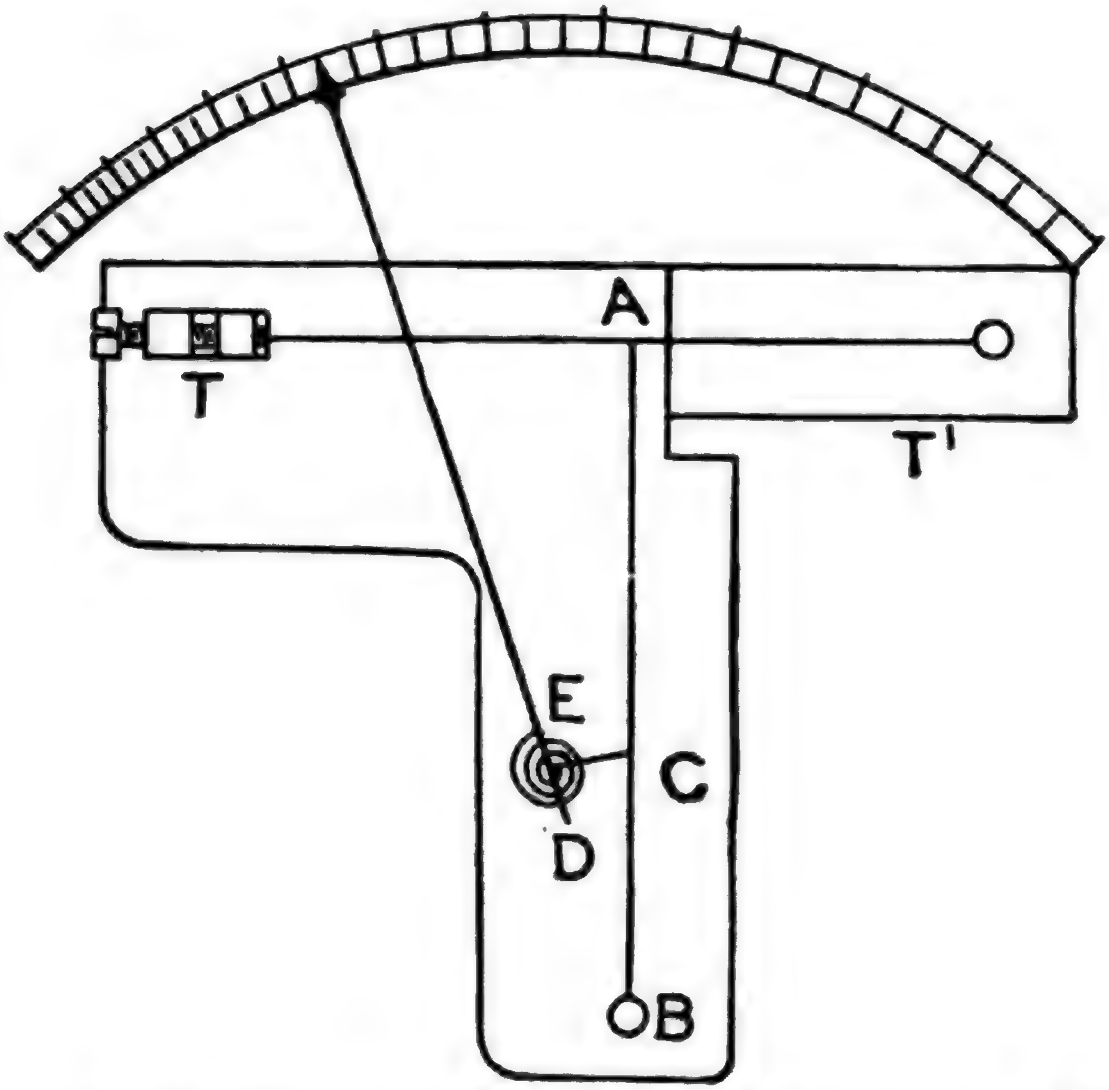


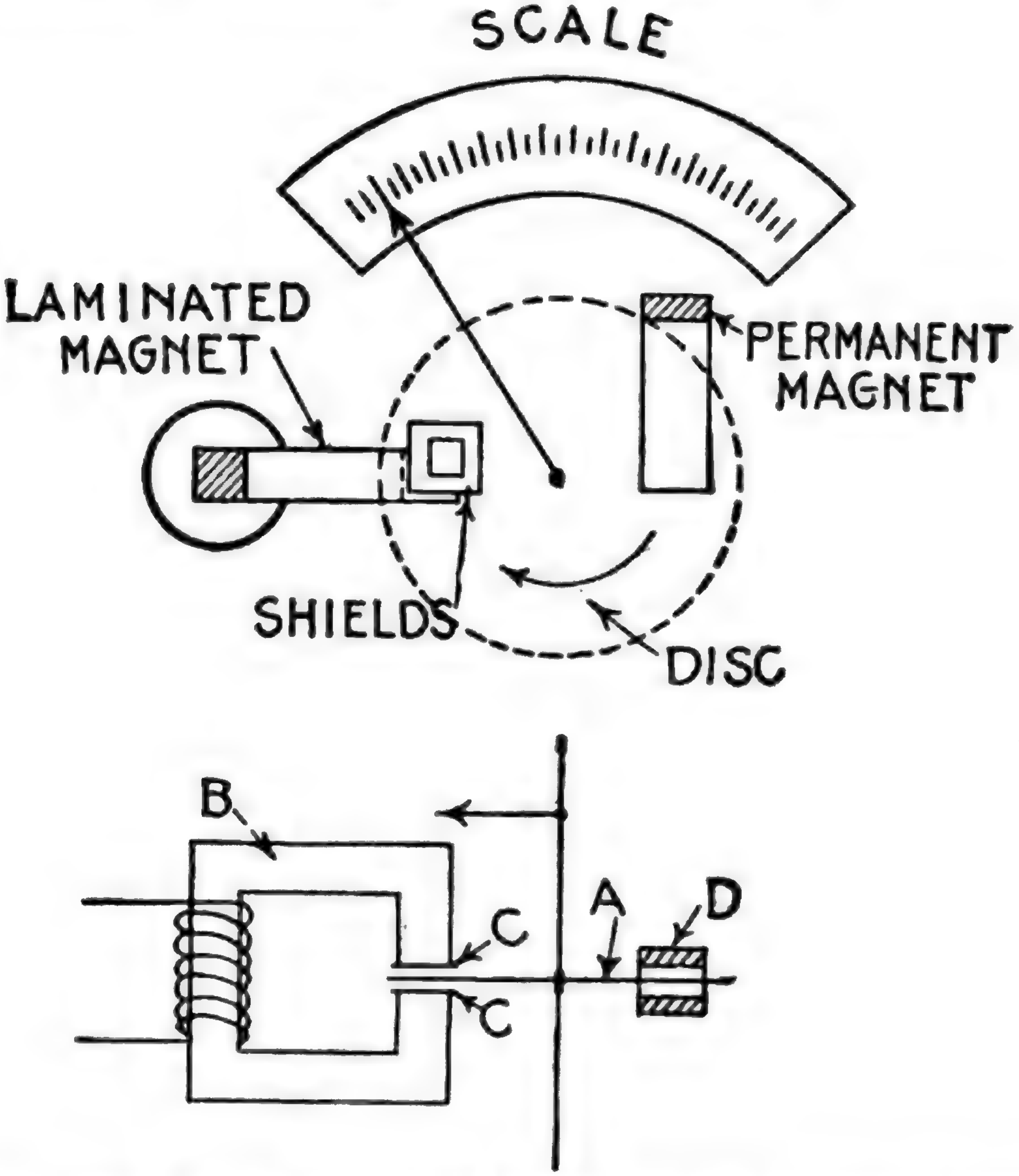
FIG. 2,504.—Diagram illustrating the principle of hot wire instruments. The essential parts are the active wire A, stretched between terminals T and T', tension wire C, thread E, and pulley D to which is attached the pointer.

Induction Instruments.—These were invented by Ferraris, and are sometimes called after him. They are for alternating current only, and there are two forms:

1. Shielded pole type;
2. Rotary field type.

Ques. Describe the shielded pole type of induction instrument.

Ans. As shown in figs. 2,505, and 2,503 it consists, essentially of a disc A, or sometimes a drum and a laminated magnet B. Covering some two-thirds of the pole faces are two copper plates or shields C, and a permanent magnet D.



Figs. 2,505 and 2,506.—Plan and elevation of shielded pole type of induction instrument.

Ques. How does it work?

Ans. Eddy currents are induced in the two copper plates or shields C, which attract those in the disc, producing in consequence a torque in the direction shown by the arrow, against the opposing action of a spring. Magnet D damps the oscillations.

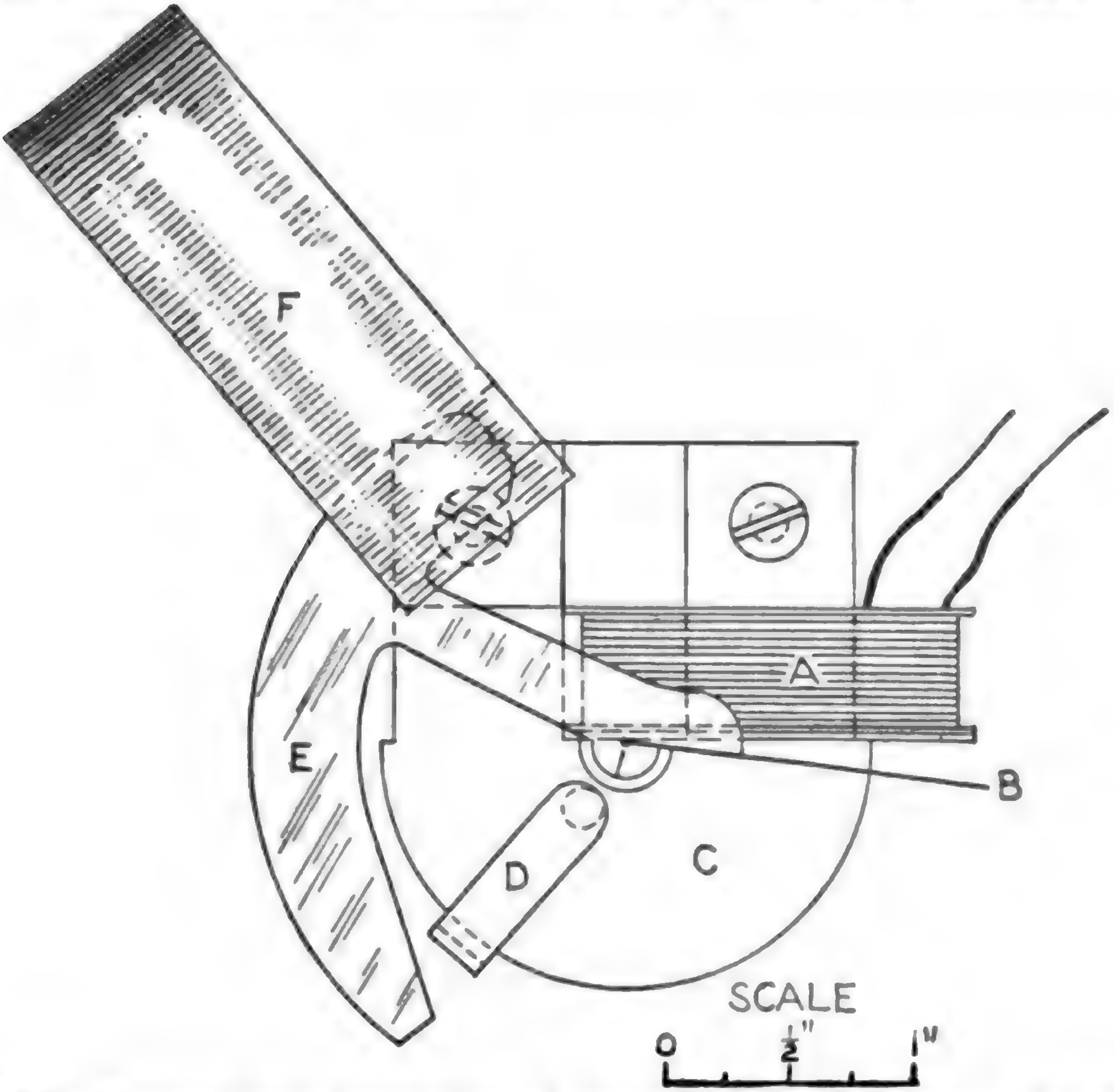


FIG. 2,507.—Diagram showing construction and operation of Hoskins instrument. It is of the modified induction type in which the torque is produced from the direct repulsion between a primary and a secondary, or induced current. As shown in the diagram, the instrument embodies the principle of a short circuited transformer, consisting of a primary or exciting coil A, a secondary or closed coil B, linked in inductive relation to the primary by a laminated iron core C, constructed to give a completely closed magnetic circuit, that is, without air gap. The secondary is so mounted with respect to the primary as to have a movement under the influence of their mutual repulsion when the primary is traversed by an alternating current. This movement of the secondary B is opposed by a spiral spring, so that the extent of movement will be dependent upon and will indicate the strength of the primary current. To increase the sensitiveness of the instrument and also to adjust the contour of the scale, an adjustable secondary D, which has an attraction effect upon the coil B, is provided upon the core. The effect of this coil is inversely proportional to its distance from the end of the swing of the coil B. The vane, E, which is a part of the stamping B, is adjusted to swing freely and with a large amount of clearance, between the poles of a permanent magnet F, which acts as a damper on the oscillation of the moving element, but does not cause any friction or affect the accuracy of the calibration. The primary, like that of a transformer, is an independent electrical circuit and may be highly insulated. This meter will withstand several hundred per cent. overload for some time because of the very high value of the self-induction and the fact that the controlling spring is not in the circuit and therefore cannot burn off.

VOLTMETER
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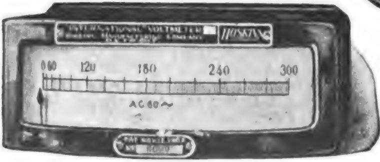
AMMETER
"INTERNATIONAL"
HOSKINS
DETROIT


INTERNATIONAL VOLTMETER
HOSKINS
0 60
120
180
240
300
AC 60~

AC 60~
VOLTMETER

FIGS. 2,508 to 2,511.—Hoskins instruments. Fig. 2,508, voltmeter, small pattern; fig. 2,509, ammeter, large pattern; fig. 2,510, voltmeter, horizontal edgewise pattern; fig. 2,511, illuminated dial voltmeter.

Ques. Describe the rotary field type of induction instrument.

Ans. The parts are arranged similar to those of wattmeters, the necessary split phase being produced by dividing the current into two circuits, one inductive and the other non-inductive.

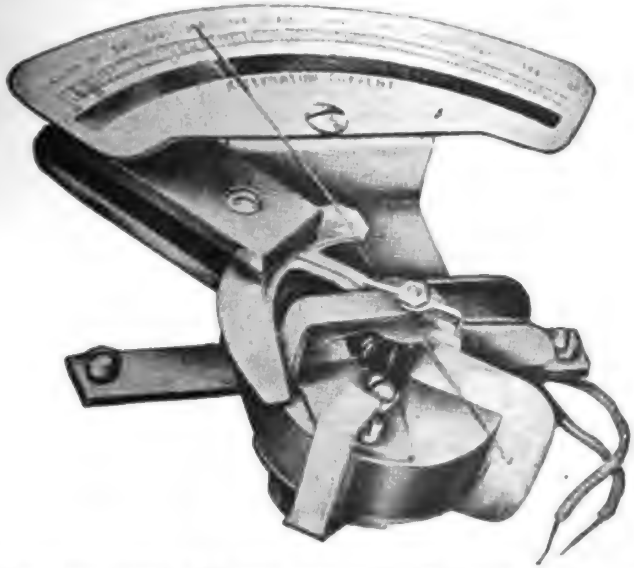


FIG. 2,512.—Hoskins instrument with case removed. It has a very short magnetic circuit which is composed of silicon steel, permitting low magnetic densities to be used.

Dynamometers.—This type of instrument is used to measure volts, amperes, or watts, and its operation depends on the reaction between two coils when the current to be measured is passed through them. One of the coils is fixed and the other movable.

Ques. Describe the construction of a dynamometer.

Ans. It consists, as shown in fig. 2,513, of a fixed coil, composed of a number of turns of wire, and fastened to a vertical support. The fixed coil is surrounded by a movable coil composed of a

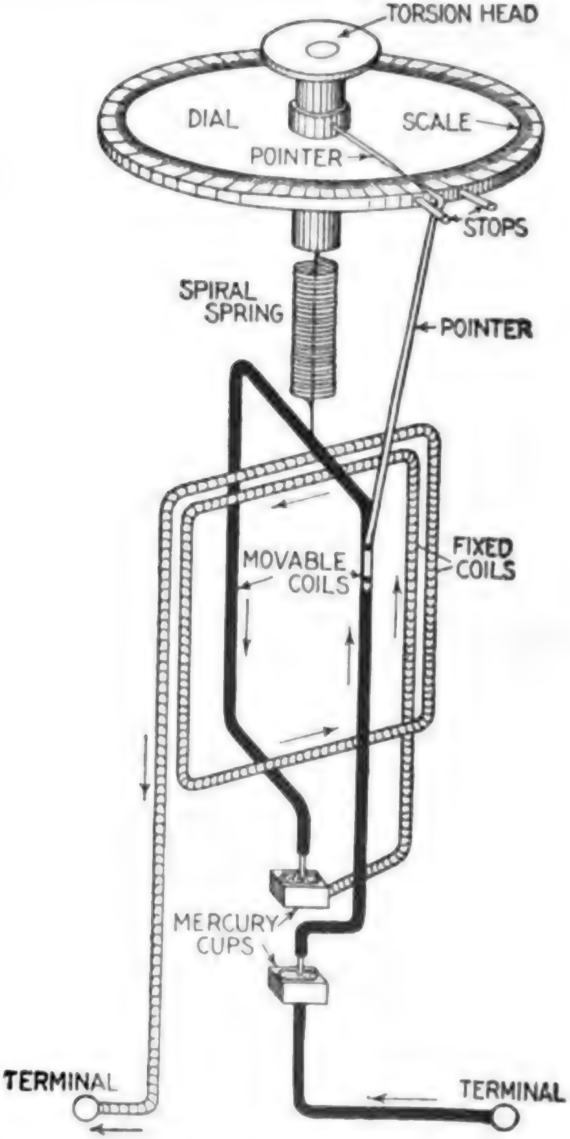

TORSION HEAD
DIAL
SCALE
POINTER
STOPS
SPIRAL SPRING
POINTER
MOVABLE COILS
FIXED COILS
MERCURY CUPS
TERMINAL
TERMINAL

FIG. 2,513.—Diagram of Siemens' dynamometer. It consists of two coils on a common axis but set in planes at right angles to each other in such a way that a torque is produced between the two coils which measures the product of their currents. This torque is measured by twisting a spiral spring through a measured angle of such degree that the coils shall resume their original relative positions. *When constructed as a* **voltmeter**, both coils are wound with a large number of turns of fine wire, making the instrument sensitive to small currents. Then by connecting a high resistance in series with the instrument it can be connected across the terminals of a circuit whose voltage is to be measured. *When constructed as a* **wattmeter**, one coil is wound so as to carry the main current and the other made with many turns of fine wire of high resistance suitable for connecting across the circuit.

few number of turns or often of only one turn of wire. The movable coil is suspended by a thread and a spiral spring attached to a tortive head which passes through the center of a dial. The ends of the movable coil dip into mercury cups, which act as pivots and electrical contacts, making connection with one end of the fixed coil and one terminal of the instrument as shown. The tortion head can be turned so as to place the planes of the

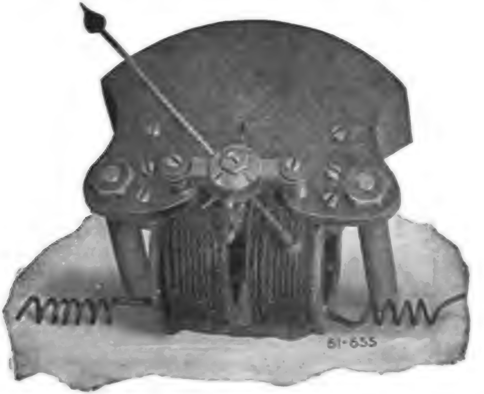


FIG. 2,514.—Wagner dynamometer movement. In this type of instrument the deflection is proportional to the square of the current, producing a constantly decreasing sensitiveness as the pressure applied is decreased. The dynamometer movement is, for any indication, more accurate than the magnetic vane, but cannot readily be employed for the indication of current, as required in ammeters.

coils at right angles to each other and to apply tortion to the spring to oppose the deflection of the movable coil for this position when a current is passed through the coils. A pointer attached to the movable coil indicates its position on the graduated dial between the two stops. Another pointer attached to the tortion head performs a similar function.

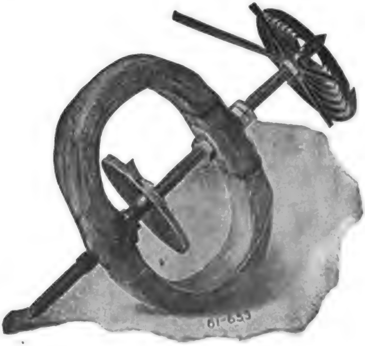


FIG. 2,515.—Armature of Wagner dynanometer movement. Greater accuracy is claimed for this movement than the magnetic vane, but it cannot readily be employed for the indication of current flow, as required in ammeters. **The magnetic vane movement** is used on the A. C. ammeter, and can be used also in the A. C. voltmeters; it makes use of its controlling spring only for the purpose of resisting the pull on the vane and the returning of the pointer to zero. The dynanometer movement is recommended for voltmeters.

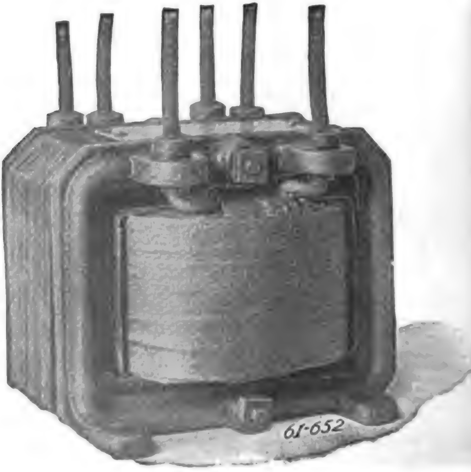


FIG. 2,516.—Wagner 25 watt pressure transformer for use with various alternating current instruments, such as voltmeters, wattmeters, etc. They are made in capacities 25, 50, 100, and 200 watts, and are built for pressures of 750 to 60,000 volts.

Ques. How does the dynamometer operate?

Ans. When current is passed through both coils, the movable coil is deflected against one of the stop pins, then the tortion head is turned to oppose the movement until the deflection has been overcome and the coil brought back to its original position.

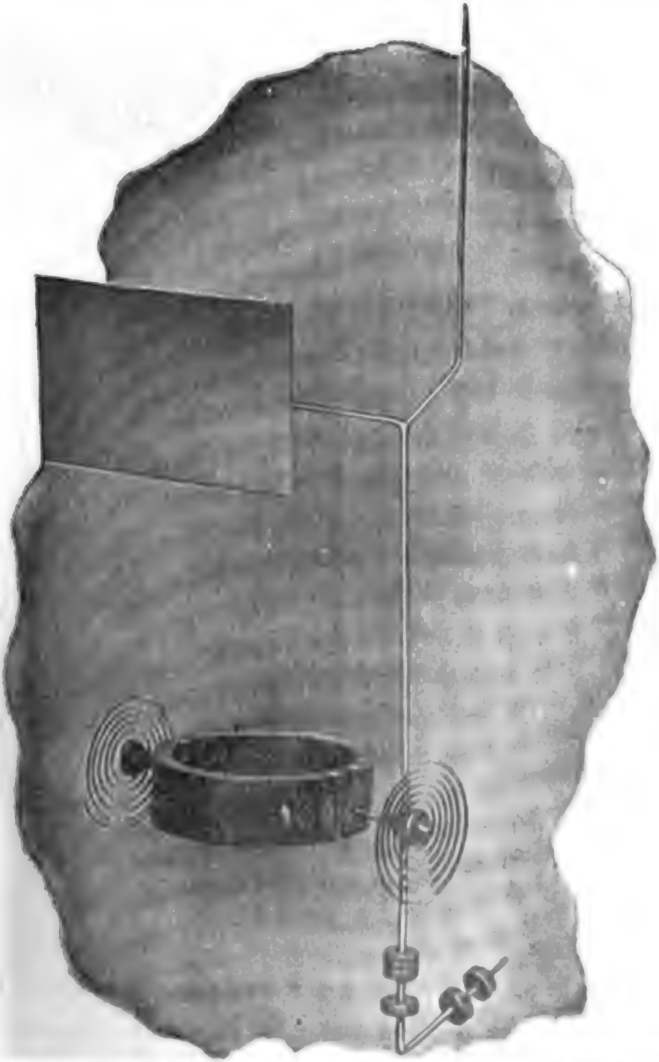


FIG. 2,517.—Moving element of Keystone dynamometer instrument. The illustration shows the movable coil, pointer, aluminum air vane for damping the oscillations, controlling springs, and counter weights.

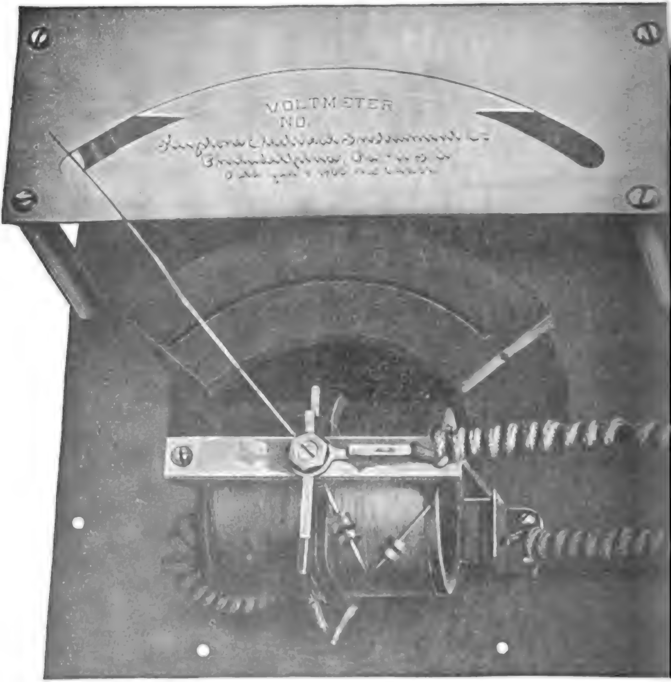


FIG. 2,518.—Keystone dynamometer movement. Since the law governing this type of ins ment is the law of current squares, it follows that in the case of voltmeters, equally divid scales cannot be obtained. In the case of **wattmeters,** the scale is approximately equa divided, due to the fact that the movement of the moving coil is proportional to the pr uct of the current in the fixed and moving coils. **The moving parts** have been made light in weight as is consistent with mechanical strength, and the entire moving system supported on jeweled bearings. The motion of the pointer is rendered aperiodic by use of an aluminum air vane moving in a partially enclosed air chamber. This meth of damping the oscillations of the moving parts renders unnecessary the use of mechani brakes or other frictional devices, which tend to impair the accuracy of the instrume The illustration shows a **voltmeter,** which, however, differs but little from a wattme In the case of a wattmeter the fixed coils are connected in series with the line, either direc or through a current transformer, while the moving coil is connected in shunt to the l

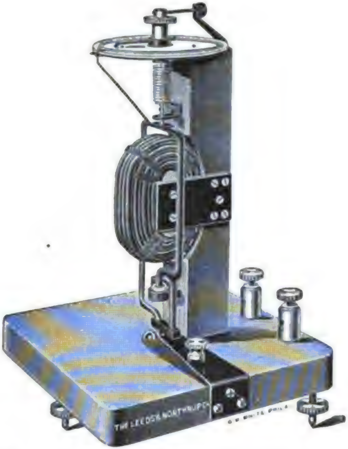


Fig. 2,519.—Leeds and Northrup **electro-dynamometer.** *It is a reliable instrument for the measurement of alternating currents of commercial frequencies.* **When wound with fine wire** and used in connection with properly wound resistances, it is equally useful for measuring alternating pressures, and may thus be employed to calibrate alternating current voltmeters as well as ammeters. **To give accurate results** the instruments must be carefully constructed and designed with a view to avoiding the eddy currents always set up by alternating currents in masses of metal near, or in the circuits. **The constant of a dynamometer** may be obtained with a potentiometer, but this is usually done with precision by the manufacturer and a certificate giving the value of the constant is furnished with the instrument. **The size and cost** of dynamometers rapidly increase with the maximum currents which they are designed to carry, and when more than 500 amperes are to be measured, the use of other instruments and methods is recommended.

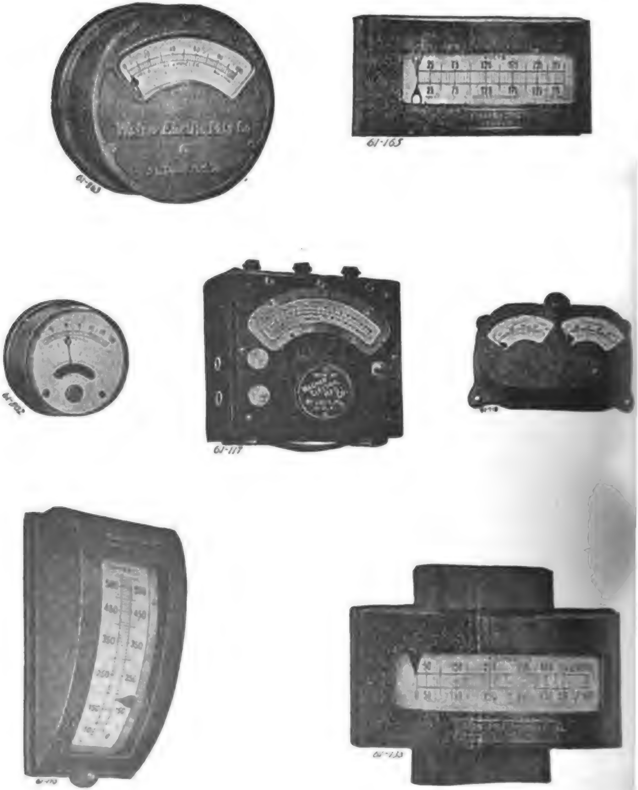
The angle through which the tortion head was turned, being proportional to the square root of the angle of tortion, the current strength in amperes is equal to the square root of the angle of tortion *multiplied by a calculated constant*, furnished by the maker of the instrument.

Ques. How is the dynamometer arranged to measure watts?

Ans. When measuring watts, the instrument should be so arranged that one coil carries the main current, and the other a small current which is proportional to the pressure.

Ques. In the construction of a dynamometer what material should not be used and why?

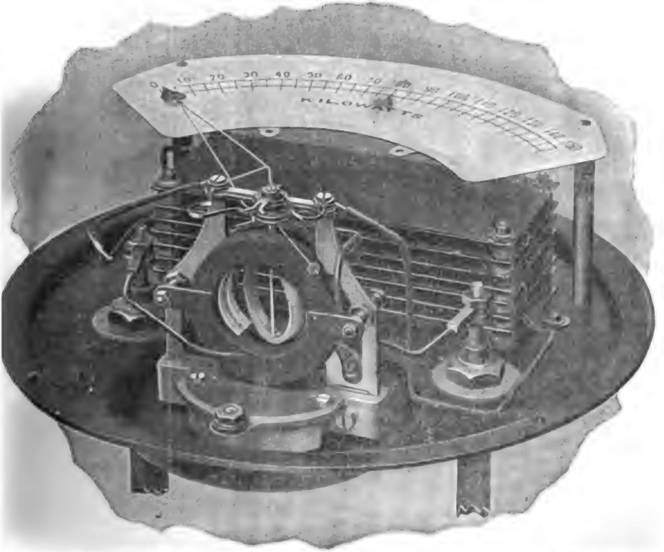
Ans. No iron or other magnetic material should be employed because of the hysteresis losses occasioned thereby. The frame should be of non-conducting material so as to avoid eddy currents.



FIGS. 2,520 to 2,526.—Various types of Wagner instruments. Fig. 2,520, small round typ fig. 2,521, horizontal edgewise type; fig. 2,522, smallest switchboard type; fig. 2,523, por able type; fig. 2,524, combination voltmeter and ammeter in one case; fig. 2,525, vertic type; fig. 2,526, polyphase type.

Watt Hour Meters.—A watt hour meter is a watt meter that will register the watt hours expended during an interval of time. *Watt hour meters are often erroneously called* **recording** *or* **integrating** *watt meters.*

There are several types of the electromoter form of watt hour meter, which may be classified as



IG. 2,527—Interior Weston single phase wattmeter. The general appearance of the dynamometer movement and the relative positions of the various parts are clearly shown. The parts are assembled on one base, the whole movement being removable by unfastening two bolts. **The fixed winding** is made up of two coils, which together produce the field of the wattmeter. **The movable coil** is wound to gauge with silk covered wire and treated with cement. While winding, the coil is spread at diametrical points to allow the insertion of the staff, which is centered by means of two curved plates cemented to the inside surface of the coil and forming a part thereof. The coil is held in a definite position by two tiny pins which pass through the staff and engage with ears on the curved plates.

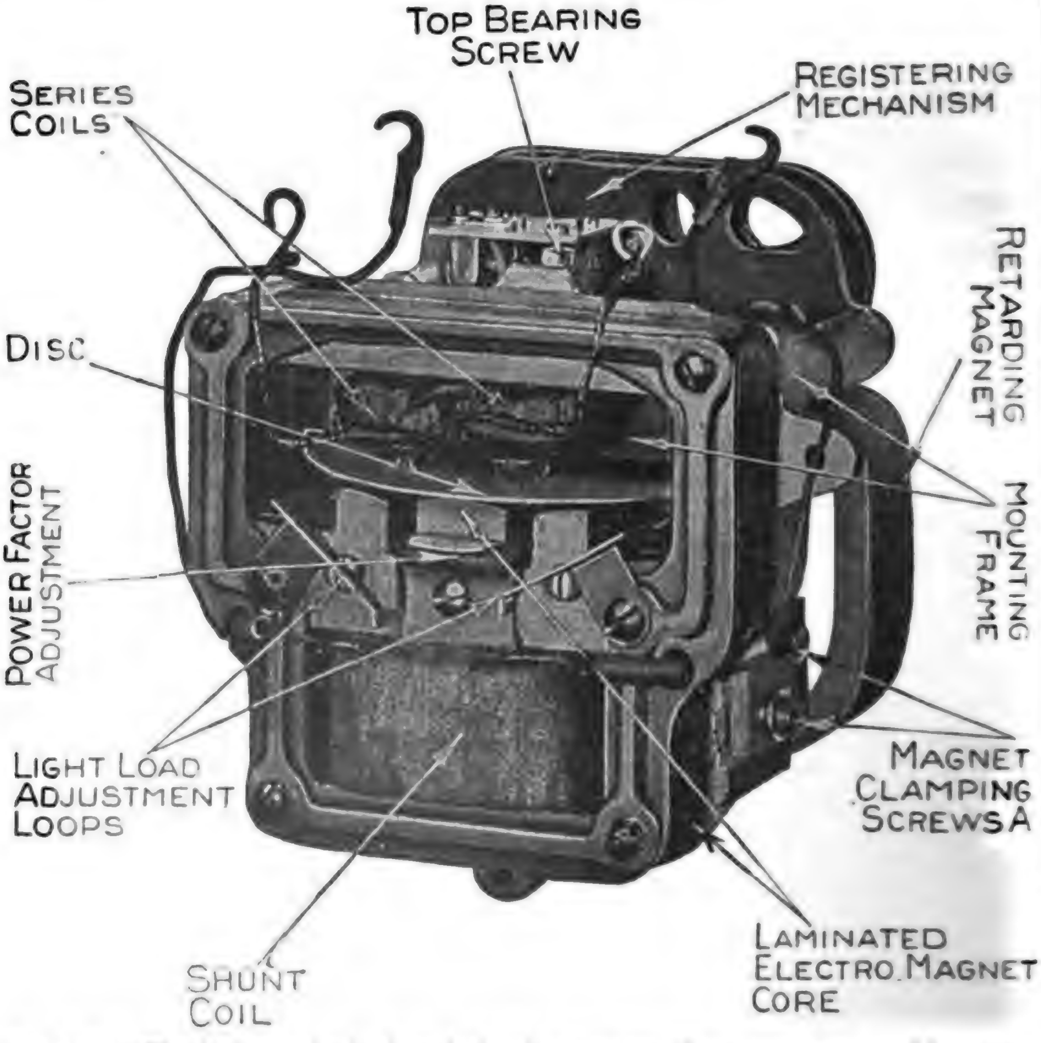

TOP BEARING SCREW
SERIES COILS
REGISTERING MECHANISM
DISC
RETARDING MAGNET
POWER FACTOR ADJUSTMENT
MOUNTING FRAME
LIGHT LOAD ADJUSTMENT LOOPS
MAGNET CLAMPING SCREWS A
LAMINATED ELECTRO MAGNET CORE
SHUNT COIL

FIG. 2,528.—Westinghouse **single phase induction type watt hour meter** removed from case. **The friction compensation**, or light load adjustment, is accomplished by slightly unbalancing the two legs of the shunt magnetic circuit. To do this a short circuited loop is placed in each air gap, and means are provided for adjusting the position of the loops so that one loop will enclose and choke back more of the flux than the other loop, and thus produce a slight torque. It will be noted that this torque depends on voltage alone, which is practically constant, and is entirely independent of the load. Adjustment is accomplished by means of either of two screws which makes micrometer adjustment possible. It is clamped when adjusted by means of a set screw, which prevents change. This method makes possible an accuracy of adjustment which effectively prevents creeping. **The power factor adjustment** consists of an adjustable compensating coil placed around the shunt pole tip. This is adjusted at the factory by twisting together the leads of the compensating coil, thus altering its resistance until the desired lagging effect is had. **Frequency adjustment.** 133 cycle meters are first calibrated on 60 cycles and the leads then untwisted to make them correct on 133 cycles. To change such a meter for use on 60 cycles it is necessary only to retwist these leads to the point shown by the condition of the wire.

1. Commutator type;
2. Induction type;
3. Faraday disc type.

Ques. What are the essential parts of a watt hour meter?

Ans. A motor, generator, and counting mechanism.

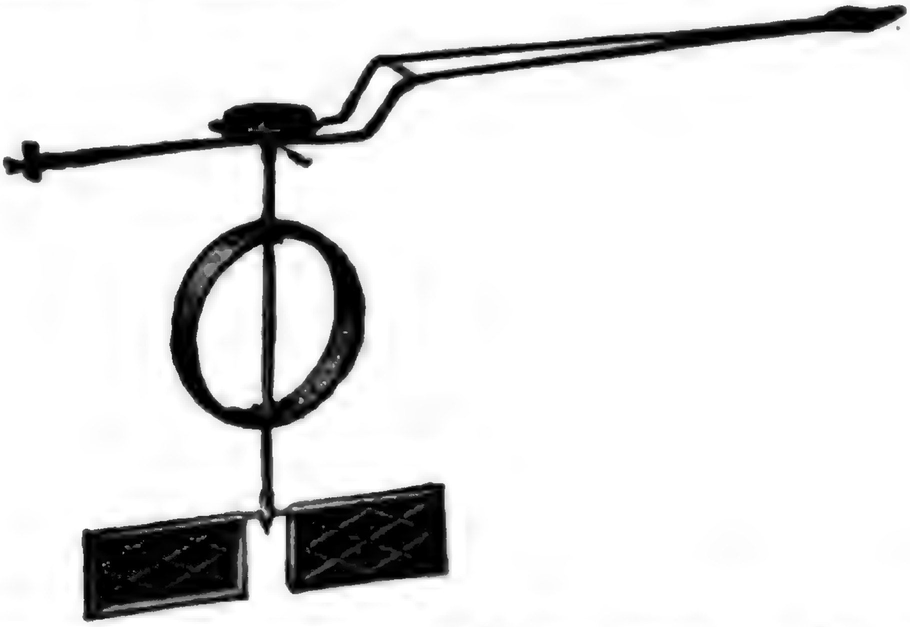


FIG. 2,529.—Pointer and movable system of Weston wattmeter. **The coil** is described in fig. 2,527. **The pointer** consists of a triangular truss with tubular members, an index tip of very thin metal being mounted at its extremity. **The index tip** is reinforced by a rib stamped into the metal. The pointer is permanently joined to a balance cross, consisting of a flat center web, provided with two short arms and one long arm, each arm carrying a nut by means of which the balance of the system may be adjusted. The longest arm, which is opposite the pointer, carries a balance nut, consisting of a thin walled sleeve provided with a relatively large flange at its outer end. The sleeve is tapped with 272 threads to the inch, the internal diameter of the sleeve being made slightly smaller than the outside diameter of the screw, and the sleeve is split lengthwise; therefore when sprung into place and properly adjusted it will remain permanently in position. A sleeve which is forced over the end of the staff carries the pointer firmly clamped between a flanged shoulder and a nut. By perforating the webb plate of the balance cross with a hole having two flat sides that fit snugly over a similarly shaped portion of the sleeve, the pointer is given a definite and permanently fixed angular position. **The air damper** consists of two very light symmetrically disposed vanes, which are enclosed in chambers made as nearly air tight as possible. These vanes are formed of very thin metal stiffened by ribs, stamped into them and by the edges, which are bent over to conform to the surface of the side walls of the chambers. They are attached by metal eyelets to a cross bar carried on a sleeve similar in construction to the one at the upper end of the staff. This cross bar is held in place by a nut, and is provided at the center with a hole having two flat sides, being similar in shape to the one in the balance cross. This hole likewise fits over a sleeve and definitely locates the vanes with reference to the other parts of the system. The damper box is cast in one piece to form the base that carries the field coils and the movable system.

Ques. What is the function of the motor?

Ans. Since the motor runs at a speed proportional to the energy passing through the circuit, it drives the counting mechanism at the proper speed to indicate the amount of energy consumed.

Ques. What is the object of the generator?

Ans. It furnishes a suitable counter torque or load for the motor.

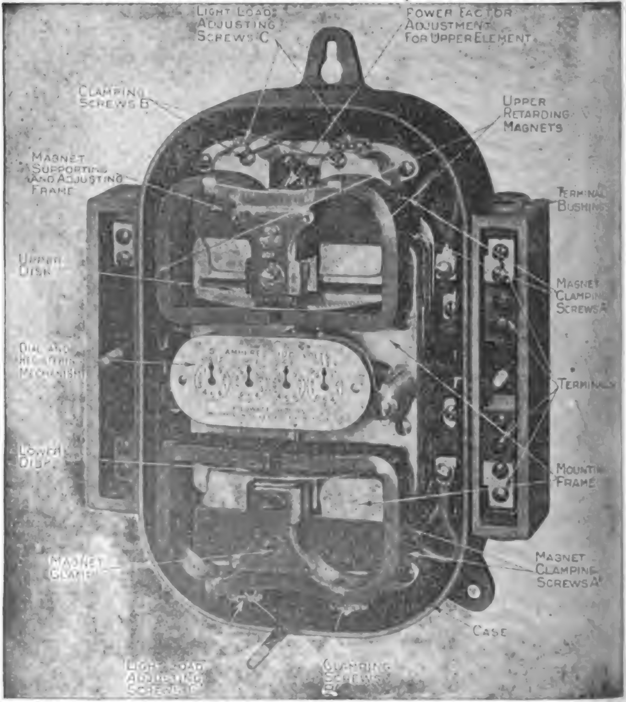

Light Load Adjusting Screws C
Power Factor Adjustment for Upper Element
Clamping Screws B
Upper Retarding Magnets
Magnet Supporting and Adjusting Frame
Terminal Bushin
Upper Disk
Magnet Clampin Screws A
Dial and Registering Mechanism
Termin
Lower Disk
Mountin Frame
Magnet Clamp
Magnet Clamping Screws A
Case
Light Load Adjusting Screws C
Clamping Screws B

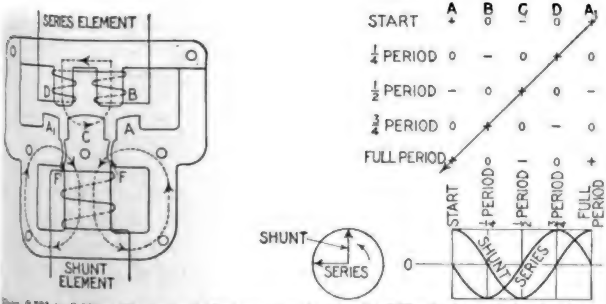
Fig. 2,530.—Westinghouse polyphase induction type watt hour meter, covers removed. This type is made for two phase three wire and four wire, and three phase three wire and four wire circuits. Meters for circuits of more than 300 amperes or 500 volts require transformers, but, like the self-contained meters, are calibrated to read directly in kilowatt hours on the dial, without a multiplying constant.

Ques. Is there any other resistance to be overcome by the motor?

Ans. It must overcome the friction of all the moving parts.

Ques. Is the friction constant?

Ans. No.



	A	B	C	D	A_1
START	+	0	−	0	+
¼ PERIOD	0	−	0	+	0
½ PERIOD	−	0	+	0	−
¾ PERIOD	0	+	0	−	0
FULL PERIOD	+	0	−	0	+

FIGS. 2,531 to 2,533.—Diagram of electro-magnetic circuit of Westinghouse induction type watt hour meter, and diagram showing rotation of field. The dotted lines show the main paths of the magnetic flux produced by the two windings, the directions, however, are constantly reversing owing to the alternations of the current in the coils. Denoting the shunt and series pole tips by the letters as shown, a clear statement of the relation of the fields for each quarter period may be given. The signs + and − represent the instantaneous values of the poles indicated. Thus, **at one instant** the shunt pole tips A, C, and A_1 are maximum +, −, and +, respectively because the instantaneous value of the current is maximum, while the value of the series flux is zero. **At ¼ period later** the shunt current is zero, giving zero magnetic pressure at the pole tips, while the series current has reached a maximum value, giving maximum − and + at the pole tips B and D. **At the next ¼ period** the shunt current is again maximum, but in a direction opposite to what it was at the beginning, making the pole tips A, C, and A_1 +, −, and +, respectively, while the series current again is zero, etc., the values for the complete cycle being given in fig. 2,533. It will be observed from the table that both the + and − signs move constantly in the direction from A_1 to A, indicating a shifting of the field in this direction, the process being repeated during each cycle.

Ques. What provision is made to correct the error lue to friction?

Ans. The meter is compensated by exciting an adjustable uxiliary field from the shunt or pressure circuit.

Ques. What is the construction of the generator?

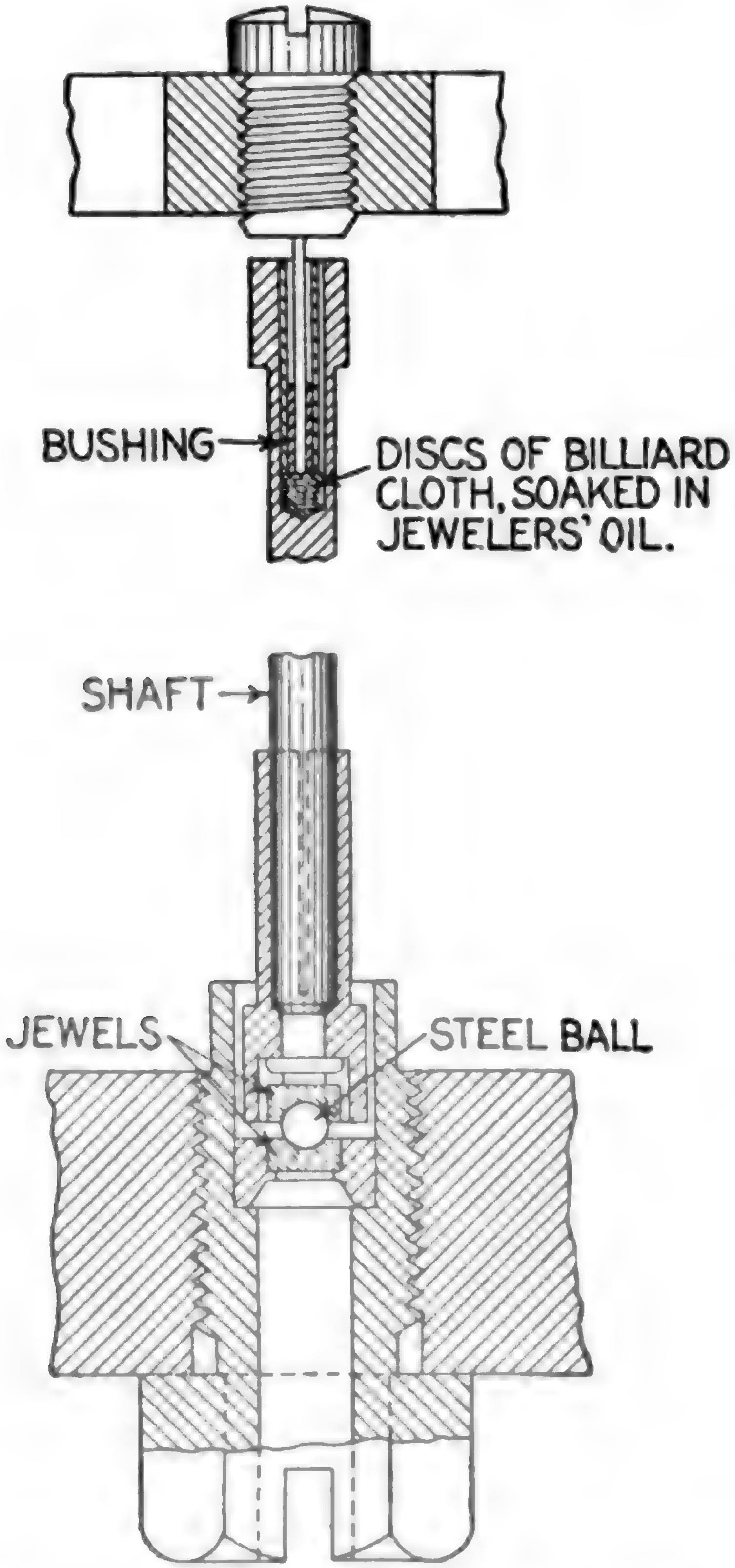
Ans. In nearly all meters it consists of a copper or aluminum disc carried on the same shaft with the motor and rotated in a magnetic field of constant value.

Ques. How is the counter torque produced?

Ans. When the disc is rotated in the magnetic field, eddy currents are induced in the disc in a direction to oppose the motion which produces them.

Ques. For what services is the commutator type meter used?

Ans. It is used on both direct and alternating current circuits.



FIGS. 2,534 and 2,535.—Cross section of bearings of Westinghouse induction type watt hour meter. The lower bearing consists of a very highly polished and hardened steel ball resting between two sapphire cup jewels, one fixed in the end of the bearing screw and the other mounted in a removable sleeve on the end of the shaft. Owing to the minute gyrations of the shaft the ball has a rolling action, which not only makes a lower friction coefficient than the usual rubbing action, but presents constantly new bearing surfaces and thus produces long life. The upper bearing is only a guide bearing to keep the shaft in a vertical position, and is subject to virtually no pressure, and consequently little friction. It consists of a steel pin fastened to a removable screw and projecting down into a bushing in a recess drilled in the shaft. The bottom of this recess is filled with billiard cloth saturated with watch oil. A film of oil is maintained around the pin by capillary action.

Ques. What is the objection to the commutator meter?

Ans. The complication of commutator and brushes, and the fact that the friction of the brushes is likely to affect the accuracy of the meter.

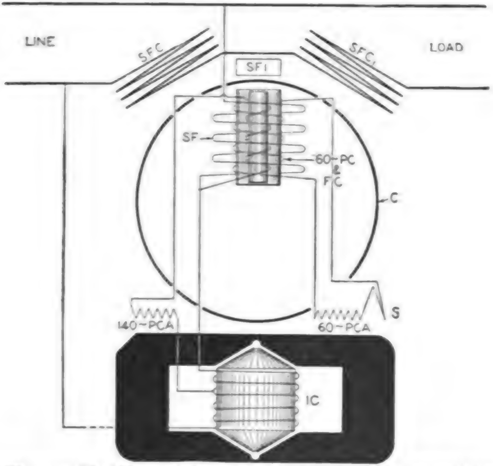


FIG. 2,536.—Diagram of Fort Wayne, induction watt hour meter. **It is designed** to register the energy of alternating current circuits regardless of the power factor, **and embodies** ***the usual induction motor, eddy current generator and registering mechanism.*** The electrical arrangement of the meter consists of ***a current circuit*** composed of two coils connected in series with each other and in series with the line to be measured, and ***a pressure circuit*** consisting of a reactance coil and a pressure coil connected in series with each other and across the line to be measured. In addition, the pressure circuit contains a light load coil wound over a laminated sheet steel member, adjustably arranged in the core of the pressure coil and connected across a small number of turns of the reactance coil so as to give a field substantially in phase with the impressed pressure. The light load winding is further provided with a series adjustable resistance furnished for the purpose of regulating the current flowing in the light load winding, thereby providing a means of lagging the meter on high frequencies, such as 125 or 140 cycle circuits. The pressure circuit also comprises a lag coil wound over the upper limb of the core of the pressure circuit and provided with an adjustable resistance for obtaining a field component in quadrature with the shunt field.

Ques. What are its characteristics?

Ans. It is independent of power factor, wave form, and frequency when no iron is used in the motor.

Ques. What meter is chiefly used on A. C. circuits?

Ans. The induction meter.

Principles of Induction Watt Hour Meters.—Every commercial meter of this type is made up of a number of elements,

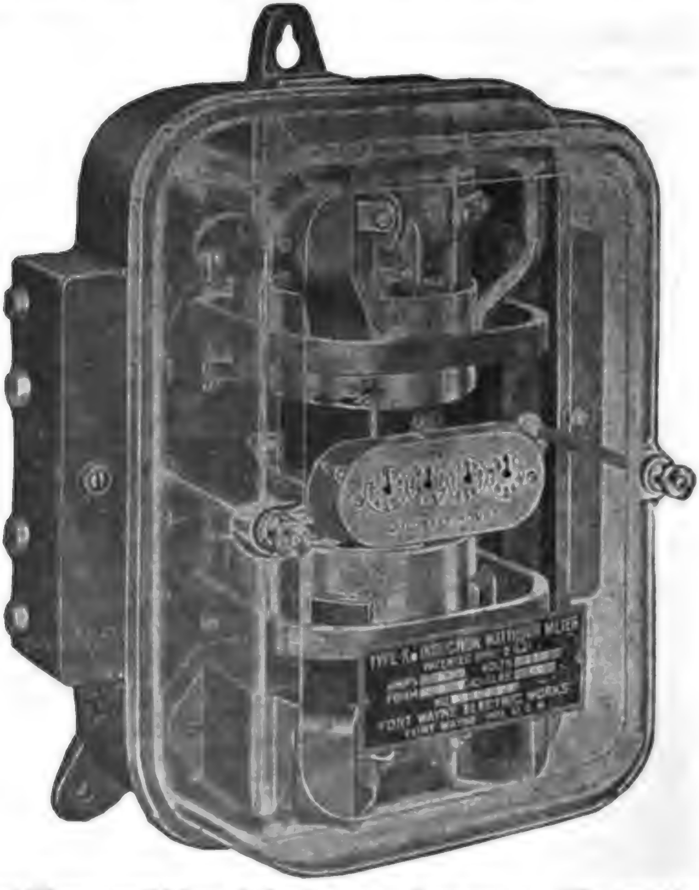
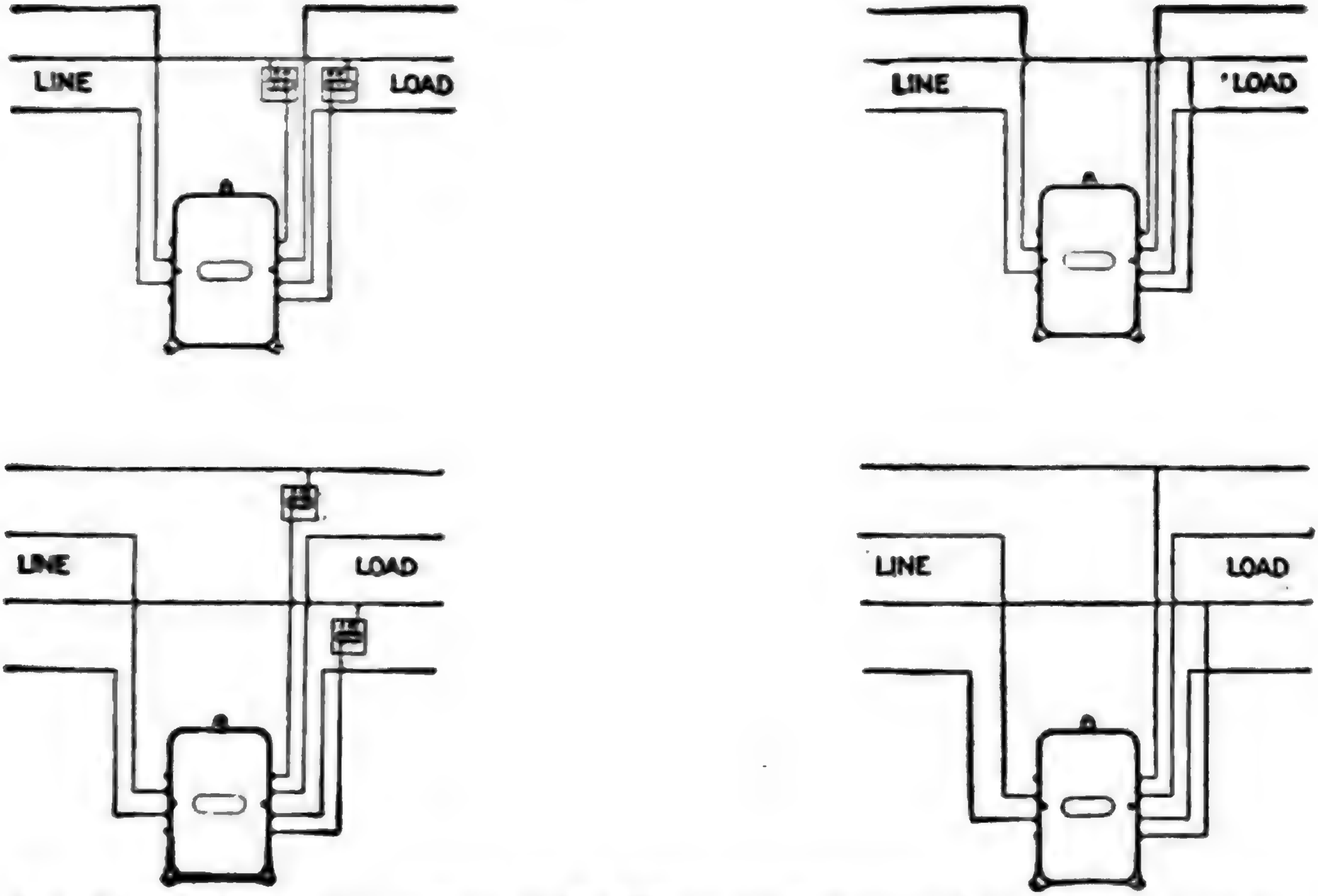


FIG. 2,537.—Fort Wayne multiphase induction watt hour meter. **The construction of the mechanism** *is essentially two single phase motor elements*, one at the bottom of the meter in a suitable position, the other inverted and placed at the top of the meter. **Each element** acts on a separate cup, but both cups are mounted on a single shaft so that the registration is due to the resultant torque of the two elements. The meter is provided with three supporting lugs, the one at the top being keyholed and one of the bottom two, slotted to facilitate leveling. **The registering mechanism** is mounted on a cast iron bracket at the middle of the meter between the two motor elements. The supporting bracket is attached to the meter base by two screws and aligned by two dowel pins. The register is of the four dial type, reading in kilowatt hours. Each division of the right hand circle, or that passed over by the most rapidly moving pointer, equals one kilowatt hour in meters without a dial constant. In meters of larger capacities, dial constants of 10, 100 and 1,000 are used, in which case it is only necessary to add one, two or three ciphers to the observed reading.

described below. Each of these elements and parts has certain functions, and each is therefore necessary to the successful operation of the meter; moreover, each element, unless correctly designed, may introduce a source of inaccuracy. These elements are:

1. The field producing element;
2. The moving element;
3. The retarding element;



FIGS. 2,538 to 2,541.—Connections of Fort Wayne multi-phase watt hour meters (type K_3—forms MAB and MAK), for 100–625 volt circuits, 5–150 amperes. *Fig.* 2,538 two and three phase, three wire circuit, 25-36 cycles; fig. 2,539 two and three phase, 3 wire circuit, 36 cycles and above; fig. 2,540, two phase 4 wire circuit, 25–36 cycles; fig. 2,541 two phase, 4 wire circuit 36 cycles and above.

4. The registering element;
5. The mounting frame and bearings;
6. The friction compensator;
7. The power factor adjustment;
8. Frequency adjustment;
9. **The case and cover.**

1. The Field Producing Element.—This consists of the electro-magnetic circuit and the measuring coils. One of these coils, connected in series with the circuit to be metered, is wound of few turns and is therefore of low inductance. The current through it is in phase with the current in the metered circuit. The other coil, connected across the circuit, is highly inductive, and therefore the current in it is nearly 90 degrees out of phase with, and proportional to the voltage of the metered circuit

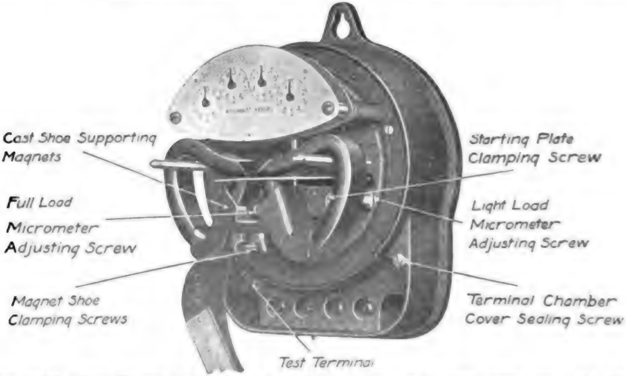

Cast Shoe Supporting Magnets
Full Load Micrometer Adjusting Screw
Magnet Shoe Clamping Screws
Starting Plate Clamping Screw
Light Load Micrometer Adjusting Screw
Terminal Chamber Cover Sealing Screw
Test Terminal

FIG. 2,542.—Fort Wayne single phase induction watthour meter with cover removed. The rotating parts consist of an aluminum disc mounted on a short shaft of small diameter. The lower end has inserted in it a hardened steel pivot which rests in a cup shaped jewel bearing. The top of the meter shaft is drilled and provided with a small washer having the central hole of very small diameter. Into this hole there extends a steel pin around which the shaft turns. Two micrometer screws are provided for load adjustment—one for the full load and the other for the light load adjustment. The adjustment for accuracy on full load is secured by varying the position of the permanent magnets, sliding them either in or out from the center of the rotating disc of the meter depending on whether it is desired to increase or decrease the speed of the disc. The micrometer screw shown in the figure serves to vary the position of the permanent magnets, causing the shoe in which the two magnets are firmly clamped to slide on the milled magnet support which is cast as an integral part of the meter frame. When the proper position of the magnets has been accurately determined by adjustment and test, the shoe which holds the two magnets is clamped firmly to the milled magnet support by two screws, one of which is shown in the figure. The adjustment for accuracy on light load is secured by varying the position of a metal punching, known as the starting plate, laterally under the pressure pole in the path of the pressure flux. This lateral movement is accomplished by means of the micrometer screw. When the proper position of this punching has been accurately determined by adjustment and test, it is secured in place by tightening the two brass screws which serve to clamp it to the meter frame.

across its terminals. Therefore, when the current in the circuit is in phase with the voltage (100 per cent. power factor) the currents in the meter coils are displaced almost 90 degrees with respect to each other.

Ques. How is this angle made exactly 90 degrees?

Ans. By means of the power factor adjustment.

Ques. How are the coils mounted?

Ans. They are so mounted on the core that the currents in

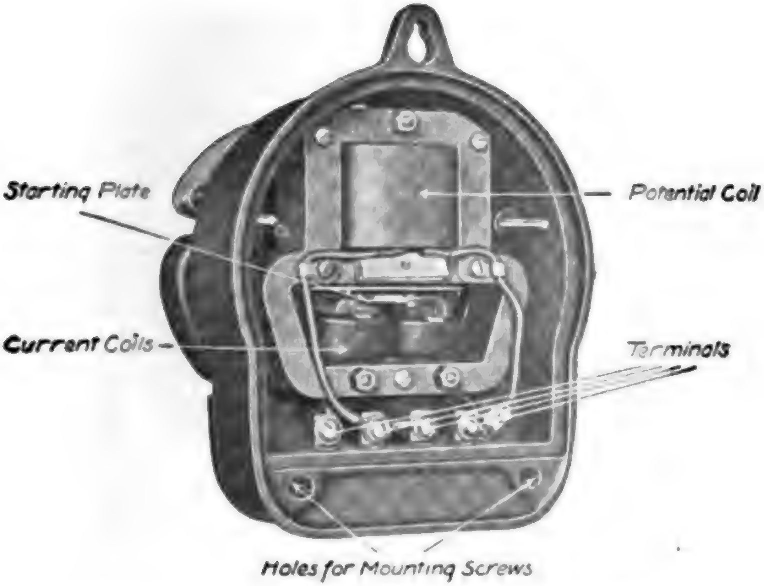


Fig. 2,543.—Rear view of Fort Wayne single phase induction watthour meter with back cover plate removed. The pressure and current coils and their respective cores lie behind the main frame of the meter. This complete electromagnetic unit can be removed as a whole from its mounting in the case. The pressure coil is wound from enameled wire, the number of turns being very high. The current coils have but few turns each and are wound from cotton covered wire. All coils are heated with insulating compound before assembling in the meters. The laminated iron cores placed within these coils are built up from magnetic steel. The magnetic circuits formed by the cores of the pressure and current coils are so arranged that they exert a high torque upon the disc of the rotating element in order that minute variations in the friction of the moving parts, which are likely to occur will not cause any appreciable error in the registration of the meter. The iron case surrounding the electrical elements protect that part of the meter from the effects of external stray fields, while the astatic arrangement of the permanent magnets tends to prevent any influence on the damping system. The fact that the iron frame of the meter lies between the permanent magnets and the current coils protects the magnets from the effects of short circuits which create a strong magnetic field within the meter itself.

them produce a rotating or shifting field in the air gap, in somewhat the same manner that the currents in the primary windings of an induction motor produce a rotating field.

Ques. What is the strength of the rotating field with 90 degrees phase difference between the currents?

Ans. It is proportional to the product of the currents in the

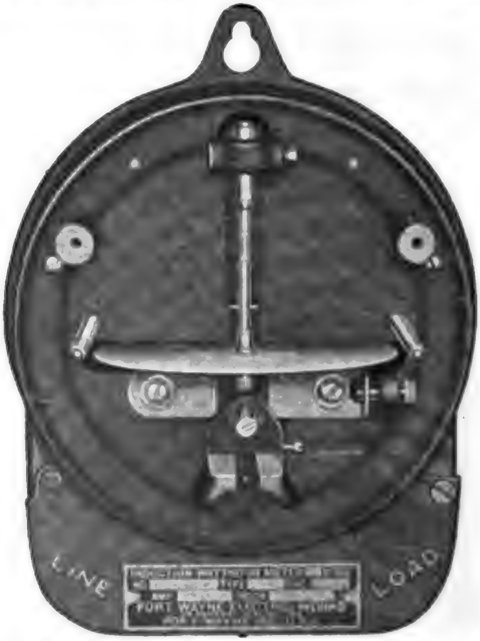


FIG. 2,544.—Fort Wayne single phase induction watthour meter with cover register and permanent magnets removed to show solid meter frame. A heavy steel back plate held in place by two screws inserted from the front of the central casting encloses the back part of the completely assembled meter. A felt gasket lying on a suitable ledge seals the joint against the entrance of dust or moisture when the back plate is drawn down firmly by the screws. The cover which encloses the back part of the meter is a non-magnetic metallic stamping. It is held in place by wing nuts on the two light brass studs extending forward from the meter frame. This joint between the main frame and the cover is also sealed against the entrance of dust and moisture by the use of a suitable felt gasket. Two glass windows are provided in this cover, one to permit the reading of the register dials, the other to permit observation of the disc's rotation. The cover is sealed in place in the usual way by passing a sealing wire through a hole drilled in the cover sealing stud and thence through a hole provided in the wing of the seal nut. The terminal chamber is an extension of the casting which supports all the inner parts of the meter. The heavy brass terminals used for connecting the meter in circuit are held permanently by a non-combustible insulating compound which is moulded in place around them. This construction gives excellent insulation and is a safeguard against accidental short circuits across terminals. A punched terminal cover which fits over the terminal chamber is hinged at the upper left hand corner so that it will of its own accord swing out of the way when the terminal cover sealing screw is removed. This hinged style of cover will be found convenient when installing and connecting the meter in circuit. When this cover is swung back into closed position it is fastened in place by passing a seal right through the seal screw and through a lug provided on the cover.

two coils and therefore proportional to the product of current and voltage in the metered circuit.

At any other power factor the field is proportional to this product multiplied by the sine of the angle of phase difference between the two meter currents. If the current in the voltage coil be in quadrature with the voltage of the metered circuit, at any power factor the sine of the angle of phase difference between the currents in the meter circuits will be equal to the cosine of the angular displacement between the current and voltage in the metered circuit. Under these conditions therefore the strength of the shifting field is proportional also to the power factor of the circuit. In other words, the strength of the rotating field is proportional to the product of the volts, amperes and power factor and is therefore a measure of the actual power.

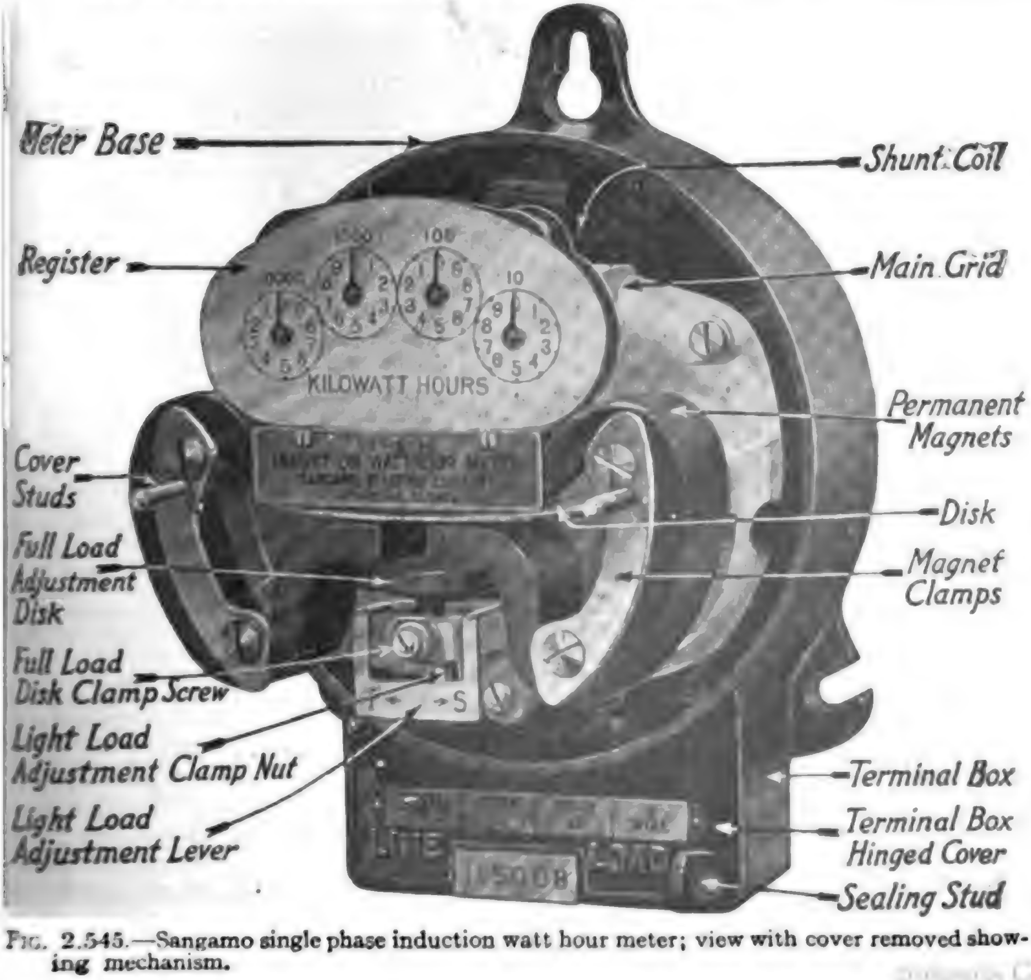

Meter Base
Shunt Coil
Register
Main Grid
KILOWATT HOURS
Permanent Magnets
Cover Studs
Disk
Full Load Adjustment Disk
Magnet Clamps
Full Load Disk Clamp Screw
Light Load Adjustment Clamp Nut
Terminal Box
Light Load Adjustment Lever
Terminal Box Hinged Cover
Sealing Stud

FIG. 2,545.—Sangamo single phase induction watt hour meter; view with cover removed showing mechanism.

Ques. In what part of the meter is energy consumed?

Ans. In the field producing element.

It is upon the design of this element that the losses in the meter depend. Current is flowing through the shunt coil continuously, even when no energy is being taken, and the higher the inductance of this coil, the smaller will be the energy component of the constant flow. The series coil causes a loss of energy proportional to the square of the current flowing. It also causes a drop in voltage, both inductive and resistive, hence, the resistance and inductance of the series coil of the meter should be as low as possible.

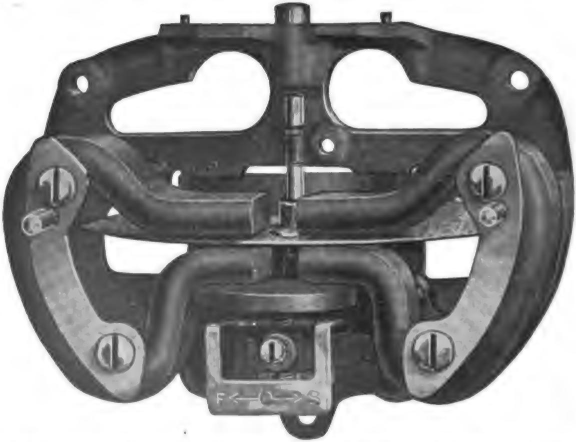


FIG. 2,546.—Main grid or supporting frame of Sangamo single phase induction watt hour meter. The grid is of cast iron and its design is such that the weight of the permanent magnets, series laminated element and return plate are carried on the main portion, the smaller projecting brackets carrying no weight except that of the moving system. The supporting grid is removed by taking out the three screws locating and holding it in position, to the iron base, also removing at the same time the screws connecting the leads of the series coils to the binding posts at the bottom. The meters are all built with four binding posts so that they may be connected either with two series leads and a tap for the pressure connection or with both sides of the circuit carried through the meter. The wire meters employ a 220 volt shunt coil, connected across the binding posts within the meter, one series coil being in each of the outer lines of the three wire system. This renders unnecessary the use of a pressure tap.

Ques. How should the magnetic circuit be designed?

Ans. The design should be such that the increase of magnetic flux with high voltage or high current will not have a retarding action but will act only to increase the torque.

If the retarding effect be not prevented, the meter will, of course, run slow at overloads. A comparative test of meters at varying load and at varying voltage will reveal the characteristics of the magnetic circuit.

2. The Moving Element.—This usually consists of a light metal disc revolving through the air gap in which the rotating field is produced.

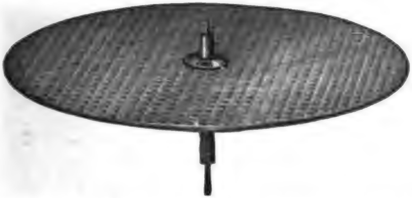


FIG. 2,547.—Moving element of Sangamo single phase induction watt hour meter. It consists of a light aluminum disc mounted on a hard brass shaft, the entire system weighing 15.6 grams. The disc is swaged under heavy pressure, to render it stiff. The arrangement of the disc, shaft, and bearings is shown in fig. 2,548. By unscrewing the upper and lower bearings the disc and shaft can be removed without disturbing the magnets or adjustments.

Ques. What is the action of the disc?

Ans. It acts like the squirrel cage armature of an induction motor, developing the motive torque for the meter.

Ques. How is this torque counter balanced?

Ans. By the retarding element so that the speed is proportional to the torque.

Ques. How should the disc be made and why?

Ans. As light as possible to reduce wear on the bearings to a minimum.

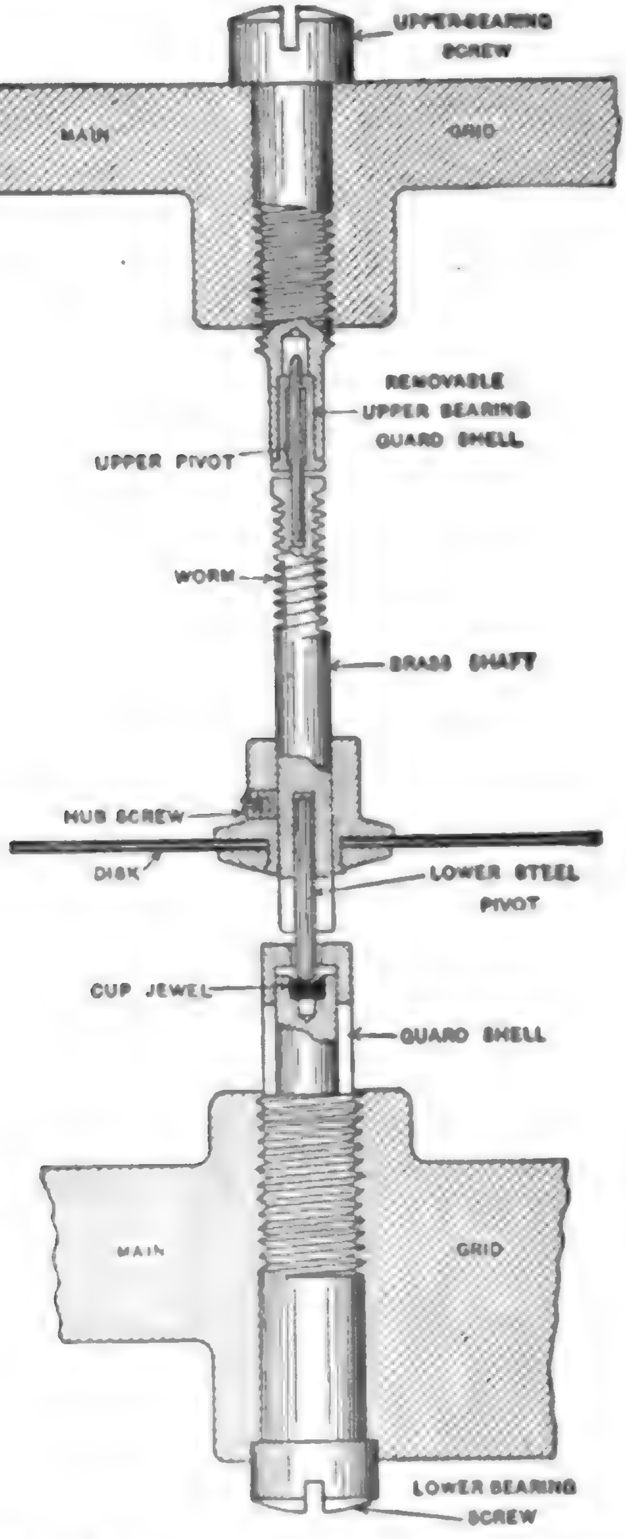

UPPER BEARING SCREW
MAIN
GRID
REMOVABLE UPPER BEARING GUARD SHELL
UPPER PIVOT
WORM
BRASS SHAFT
HUB SCREW
DISK
LOWER STEEL PIVOT
CUP JEWEL
GUARD SHELL
MAIN
GRID
LOWER BEARING SCREW

FIG. 2,548.—Bearing system of Sangamo **single phase *induction* watthour meter.** Th **upper pivot, or bearing** is made of tempered steel wire and of sufficiently small diamete be quite flexible in the length between the top of the brass shaft and the guide ring in wh rotates. The guide ring, made of phosphor bronze, has the heavy hole lined and burnish The upper bearing screw, in which the bronze bushing is carried, is so constructed that a brass sleeve closely surrounds the upper pivot of the spindle. Any blow against the m system, caused by accident or short circuit, will slightly deflect the shaft until the pivot touches against the side of the shell, thus preventing danger of breaking off or be the upper pivot. At the same time a cushioning or flexible action between the shaft the bearing shell is secured, thus eliminating the effect of vibration in the moving sy which would tend to produce rattling. **The lower bearing** consists of a cup sapphire supported in a threaded pillar, the upper end of which is provided with a sleeve so that it prevents the moving element dropping out during shipment. This protecting is held friction tight on the shaft and can be removed if it be desired to inspect the

3. The Retarding Element.—This part acts as a load on the induction motor and enables the adjustment of its speed to normal limits. In order that the speed shall be proportional to the driving torque, which varies with the watts in the circuit, it is necessary that the torque of the retarding device be proportional to the speed. For this reason a short circuited constant field generator, consisting of a metal disc rotating between permanent magnet poles, has been generally adopted.

Ques. How is the retarding torque produced?

Ans. Eddy currents are induced in the disc in rotating through the magnetic field which, according to Lenz law, oppose the force that produces them, thus developing a retarding torque.

Ques. How is the constant field for the retarding disc produced?

Ans. By permanent magnets.

The retarding disc may be the same disc used for the moving element, in which case the meter field acts on one edge while the permanent magnet field acts on the edge diametrically opposite. This arrangement simplifies the number of parts and saves space and weight of moving element.

Ques. What error is likely to be introduced by the retarding element?

Ans. If the strength of the permanent magnets change from any cause, the retarding torque will be changed and the calibration of the meter rendered inaccurate.

Ques. How may the strength of the permanent magnets be changed?

Ans. They may become weak with age, or affected by the proximity of other magnetic fields. The series coil of the meter may, under short circuit so affect the strength of the permanent magnets as to render the meter inaccurate.

Ques. What precautions are taken to keep the strength of the permanent magnets constant?

Ans. Weakening with age is prevented by the process of "Aging." The effect of neighboring fields is overcome by iron shields; this prevents the electro-magnets affecting, through overloads, the strength of the permanent magnets.

4. The Registering Element.—This mechanism comprises the dials, pointers, and gear train necessary to secure the required reduction in speed. This gear train is driven directly by the rotor and therefore its friction should be low and constant. The dials should be easily read and should register directly in kilowatt hours. If a constant be used to reduce the reading to kilowatt hours, it should be some multiple of 10, to avoid errors in multiplication. By means of suitable gears in the meters this is easily accomplished.

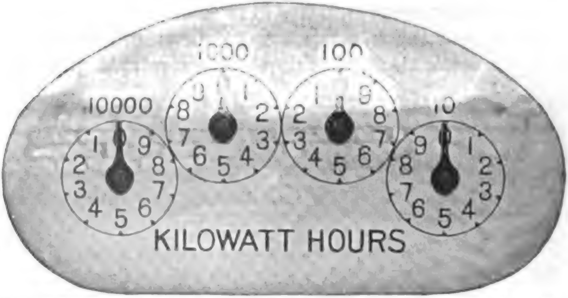


FIG. 2,549.—Register dial of Sangamo single phase induction watt hour meter (full size). The dial circles read 10, 100, 1,000, and 10,000 kilowatt hours from right to left.

5. The Mounting Frame and Bearings.—These parts have an important influence on the accuracy of the meter, as it is in the bearings that most of the friction in the meter occurs. The frame should be rigid and free from vibration, so that the bearings will be at all times in perfect alignment.

Initial friction is unavoidable in any meter construction and can be easily compensated for. A *change* in the initial friction, however, due to wear of bearings, makes readjustment necessary.

In selecting a meter the special attention should therefore be given, to the construction of the bearings, particularly the lower, or "step" bearing which supports the weight of the moving element.

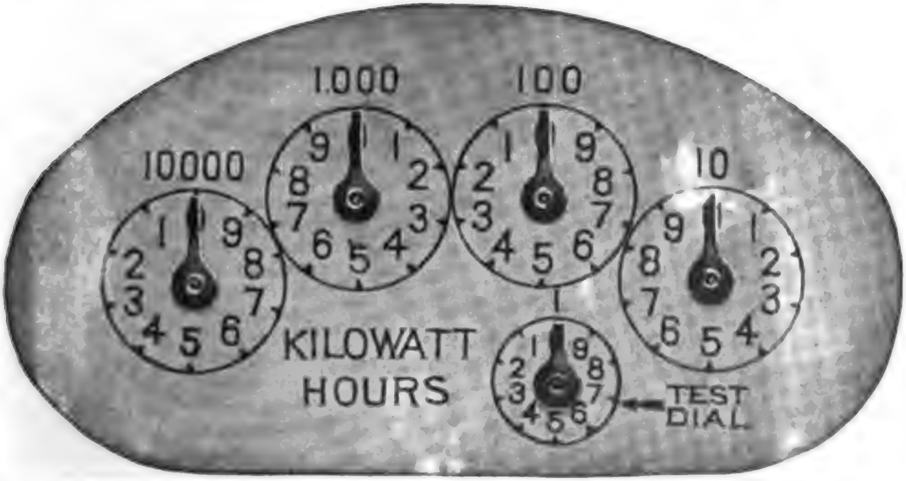


FIG. 2,550.—Canadian dial of Sangamo single phase induction watt hour meter. It has a small test circle indicating one kilowatt hour per revolution in all sizes where the first regular circle indicates 10. This is provided to conform with the requirements of the Canadian government and it is intended that the hand on the test circle shall make not less than ⅕ revolution in one hour with full load on a meter. In the case of a 10 ampere meter, it will make one complete revolution in one hour and for a 20 ampere, two revolutions, and so on. The train or indicating mechanism is carried on a rigidly formed and swaged brass bracket, accurately located by two dowel pins set in the top face of the main grid, and is held to the grid with two screws easily accessible when it is desired to remove the train for any purpose. All indicating trains used on type "H" meters are marked with symbols on the back of the train and on the compound attachment to indicate the gear ratio of each combination; this ratio being different for meters of different capacities in order to obtain a direct reading in kilowatt hours on the dial.

Ques. Describe a good construction for the step bearing.

Ans. A desirable construction would consist of a very highly polished and hardened ball with jewel seats.

6. The Friction Compensator.—The object of this device is to overcome the initial friction of the moving parts. It is evident that if this initial friction were not compensated some of the driving torque of the meter would be used in overcoming it, and the meter would therefore not rotate at very light load, and not fast enough at other loads, thus rendering the registration inaccurate, especially at light loads.

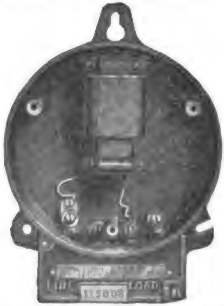


FIG. 2,551.—Base and shunt coil of Sangamo single phase induction watt hour meter. Since the shunt or pressure coil sometimes breaks down or burns out, due to abnormal line conditions or accident, provision is made for easy replacement. The shunt magnet with its coil is held to the base by two dowel pins and four screws, enabling it to be removed as a unit as shown. A new core and coil may then be substituted without the necessity of removing and replacing laminations. The shunt coil in 25 cycle meters is wider and contains more steel than the 60 and 133 cycle coils, the winding also being correspondingly increased. The return plate and series coil laminations are also changed in proportion to correspond to the increased width of the shunt magnet. The laminations forming the core are laced into the shunt coil, and subjected to enormous hydraulic pressure, the rivets being set at the same time, to form a compact unit and eliminate humming. The laminated core of the shunt element has but a single air gap in which these discs rotate.

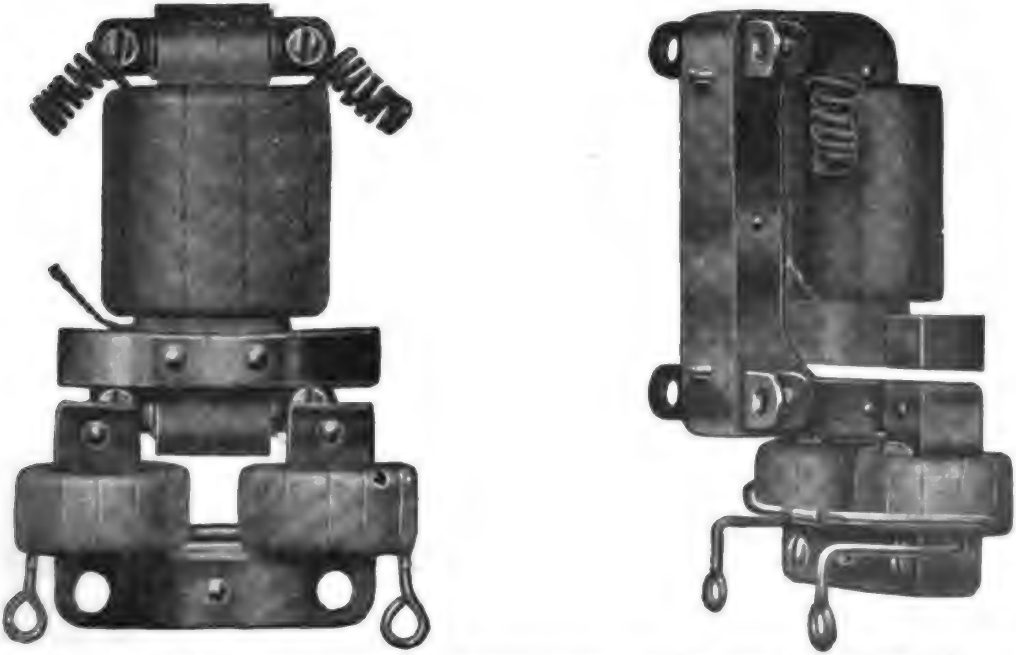
Since meters are usually run at light loads it is important that an efficient light load adjustment or friction compensator should be provided.

Ques. What important point should be considered in the design of the friction compensator?

Ans. The compensating torque must not cause the moving element to rotate or "creep" without current in the series coil.

The rotation of a meter is caused by two distinct torques, the varying meter torque, dependent on the power in the circuit, and the constant torque adjusted to compensate the initial friction.

The friction at all speeds is not exactly the same as the initial friction, and therefore the friction compensating torque may be in error a few per cent. at high speeds.



FIGS. 2,552 and 2,553.—Arrangement of magnetic circuit of Sangamo single phase induction meter. Fig. 2,552, front view; fig. 2,553, rear and side view. As shown, the gap of the shunt field in which the disc rotates, projects in between the poles of the series magnet, the return plate bending around so as to clear the upper leg of the shunt magnet. This gives the desired proximity of shunt and series fields with a maximum radius of action for both sets of field. In all capacities up to and including 60 amperes, 2 wire and 3 wire, round wire and taped series coils are used, and in capacities of 80 and 100 amperes, strap windings. Meters exceeding 100 ampere capacity have five ampere coils and are operated from external current transformers having 5 ampere secondaries. The series windings or coils are mounted on a laminated iron U shaped magnet having a laminated return path above the disc of the meter, thus forming air gaps in which the disc rotates. The series coils in all capacities not having strap windings are held firmly in position on the yoke so that they cannot slip up from the lowest position. This is accomplished by means of a pair of spring brass clips slipped through the coils on the rear face of the yoke, the clips being held by the two screws which fasten the series magnet to the main grid. As an additional precaution, spring steel lock washers are put beneath the heads of the holding screws, thus eliminating any chance of the series magnet loosening and changing position.

If the compensating torque be small compared with the driving torque, this small error percentage is negligible in its effect on accuracy. The smaller it is, the greater will be the accuracy at all loads, and therefore, as the compensating torque is adjusted to balance the initial friction the initial friction should be small compared with the driving torque.

In the wattmeter type, the phase relation between the pressure and the current fluxes is such that on a non-inductive load the torque is zero. For instance, in a dynamometer wattmeter, the pressure circuit is made highly inductive and the instrument then indicates *volts* × *amperes* × *sin φ* instead of *volts* × *amperes* × *cos φ*, that is to say, it will indicate the wattless component of the power. A dynamometer of this type is sometimes called an idle current wattmeter.

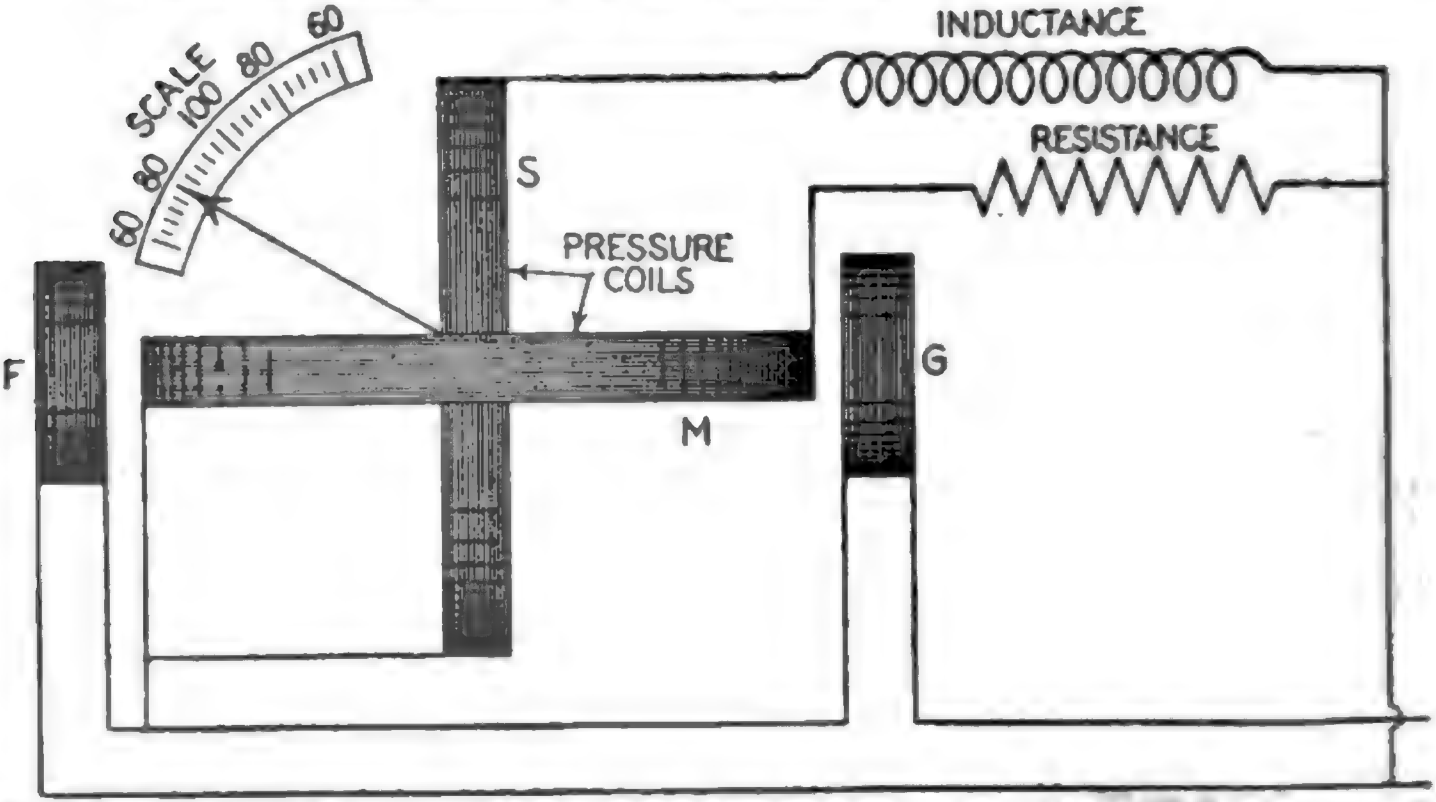


FIG. 2,579.—Single phase power factor meter of the rotating field or disc type.

Ques. Describe a single phase power factor meter of the disc or rotating field type.

Ans. It consists of two pressure coils, as shown in fig. 2,579, placed at right angles to each other, one being connected through a resistance, and the other through an inductance so as to "split" the phase and get the equivalent of a rotating magnetic field.

The coils are placed about a common axis, along which is pivoted an iron disc or vane. The magnetizing coils F6 are in series with the load. If the load be very inductive, the coil M experiences very little torque and the system will set itself as shown in the figure. As the load becomes less inductive, the torque on S decreases and on M increases so that the system takes up a particular position for every angle of lag or lead.

Ground Detectors.—Instruments of this name are used for detecting (and sometimes measuring) the leakage to earth or the insulation of a line or network and are sometimes called ***ground or earth indicators, or leakage detectors.***

For systems not permanently earthed anywhere, these instruments are nearly all based on a measurement of the pressure difference between each pole and earth, two measurements being required for two wire systems, and three for three wire, whether direct current single phase, or polyphase alternating current. **In the case of direct current** systems, the insulation, both of the network and of the individual lines, can be calculated from the readings, **but with alternating** current, the disturbance due to capacity effects is usually too great. **In any** case, however, the main showing the smallest pressure difference to earth must be taken as being the worst insulated.

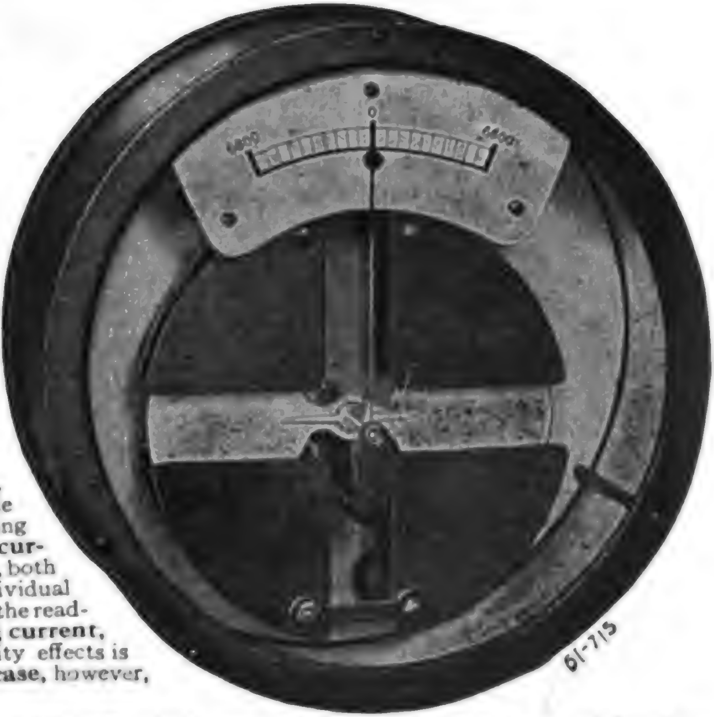
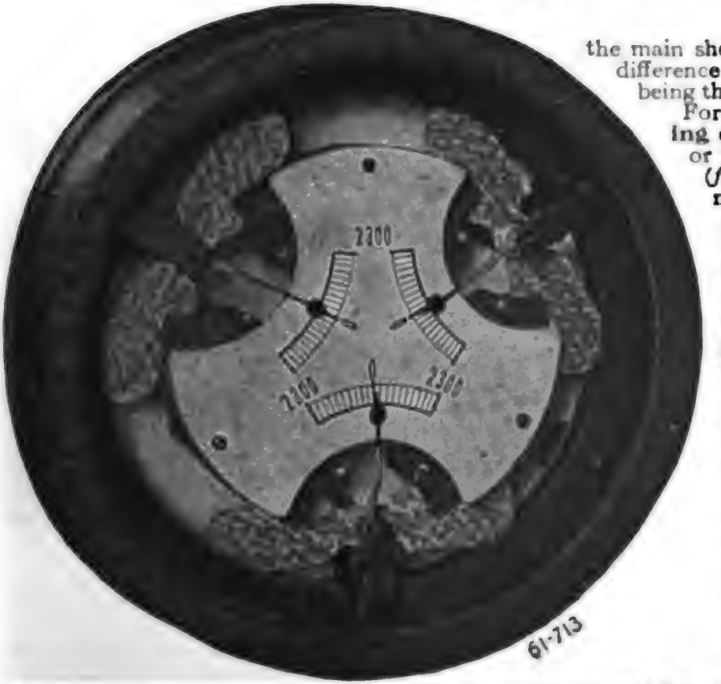


FIG. 2,580.—Westinghouse single phase electrostatic ground detector.

For low tension systems **moving coil** *(for alternating current)* or **moving iron** instruments *(for direct current)* are the most used, while for high tension systems electrostatic voltmeters are to be preferred. **On systems having some point permanently earthed** at the station, as for instance the *neutral wire* of direct current system, or the neutral point of a three phase system, an ammeter connected in the *earth wire* will serve as a rough guide. It should indicate no current so long as the insulation is in a satisfactory state, but on the occurrence of an earth it will at once show a deflection. The indications are, however, often misleading, and serve more as a warning than anything else.



ground detector.

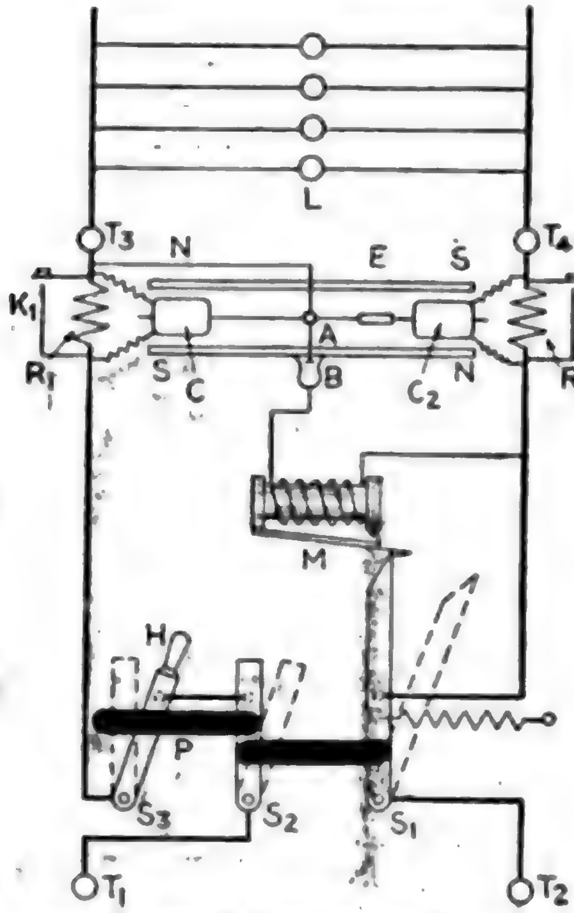


FIG. 2,582.—Wallis-Jones **automatic earth leakage cut out.** It is *an instrument which so protects a direct current circuit that the circuit is broken whenever a leak occurs from either main to earth, and so that the circuit cannot be permanently re-established until the leak has been removed.* The instrument and its connections may be explained by the aid of the accompanying diagram, in which T_1 and T_2 represent the points of connection from the mains, and T_3 and T_4, the points of connection to the circuit to be protected. S_1 S_2, and S_3 will preferably be ordinary tumbler switches, but they are diagrammatically represented as plain bar switches, their fixed contacts being diagrammatically represented by dotted circles. When the three switches S_1, S_2, and S_3 are closed, the current passes from T_1 to T_3 through the small resistance R_1, through circuit L to T_4, and back through the resistance R_2 to T_2. In shunt with R_1 and R_2, are the two moving coils C and C_2, working in the magnetic field of the magnets NS, NS, and rigidly fixed on one spindle, which is broken electrically by an ebonite block E. The points of connection to the shunts are adjusted so that when the same current passes out through one and back through the other, the effect on the two coils is equal and opposite, and there is thus no movement. Should, however, any minute portion of the current through R_1 leak to earth instead of returning via R_2, the balance is disturbed, C becomes stronger than C_2, the system is deflected, and a contact is made by the arm A at B, no matter in which direction the coils deflect. The system is similarly deflected for a leak on the other lead. In the diagram these contacts are shown at right angles to their normal plane. As soon as the contact is made, the electromagnet M is energized, the arm of S_1 is released and the spring at once pulls it off its contact, at the same time breaking S_2. The positions of the blades when the switches are open are shown dotted. The only means the user has of closing the circuit is by putting on S_3 by the handle H, which is outside the locked box. The first effect of putting on S_3 is to break its circuit; it then by means of the slotted bar P begins to pull on S_2 and S_1, which can thus be closed again, and held closed by the trigger as before. The circuit, is, however, still broken till S_3 is pushed back. Then if the leak be still on, the slot in P allows S_1 and S_2 to open at once as before. It is therefore impossible to keep the circuit closed while the leak exists. The working condition of the instrument can be tested at any time by switching a lamp on in the circuit and depressing one of the keys K_1, K_2. This short circuits R_1 or R_2, throws the coils out of balance, and the switch opens. The contact arm is closed in an inner dust tight case, and it will be noted that it *makes* contact only; the *break* occurs at the switches, thus avoiding any sparking. Since the two coils work in the two gaps of one and the same field, changes in the strength of the magnets have no effect, the apparatus is enclosed in a locked metallic box, and the only part to which the user has access is the handle H, and, if desired, the testing keys K_1 K_2.

THE THOUGHT IS IN THE QUESTION THE INFORMATION IS IN THE ANSWER

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FOR ENGINEERS, ELECTRICIANS, STUDENTS
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A PRACTICAL TREATISE

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HAWKINS AND STAFF

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Transformers; selection; efficiency; kind of oil used; detection of moisture; drying oil; regulation; transformers in parallel; polarity test—**motor generators;** various types and conditions requiring same—**dynamotors;** precautions—**rotary converters;** objections to single phase type; operation when driven by direct current, by alternating current; most troublesome part; efficiency; overload; starting; starting current.

Electrical measuring instruments; location; readings; station voltmeters; points relating to ammeters; attention necessary; usual remedies to correct voltmeter—**how to test generators;** commercial efficiency; various tests.

Station Testing: resistance measurement by "drop" method—methods of connecting ammeter voltmeter and wattmeter for measurement of power—**motor testing:** single phase motor—three phase motor, voltmeter and ammeter method; two wattmeter method; polyphase wattmeter method; one wattmeter method; one wattmeter and Y box method—three phase motor with neutral brought out; single wattmeter method—temperature test, three phase induction motor—**three phase alternator testing:** excitation or magnetization curve test—synchronous impedance test—load test—three phase alternator or synchronous motor temperature test—**direct current motor** or **generator testing:** magnetization curve—(shunt) external characteristic—direct current motor testing; load and speed tests—temperature test, "loading back" method—**compound dynamo**

MANAGEMENT—*Continued*

testing: external characteristic, adjustable load — **transformer testing:** core loss and leakage or exciting current test — copper loss — copper loss by wattmeter measurement and impedance — temperature — insulation — internal insulation — insulation resistance — polarity — winding or ratio tests.

CHAPTER LXIII

WAVE FORM MEASUREMENT

The great importance of the wave form in alternating current work is never denied, though it has sometimes been overlooked. The application of large gas engines to the driving of alternators operated in parallel requires an accurate knowledge of the wave form, and a close conformation to a sine wave if parallel operation is to be satisfactory. It is also important that the fluctuations in magnetism of the field poles should be known, especially if solid steel pole faces be used.

If an alternator armature winding be connected in delta, the presence of a third harmonic becomes objectionable, as it gives rise to circulating currents in the winding itself, which increase the heating and lowers the efficiency of the machine.

That the importance of having a good wave form is being realized, is proved by the increasing prevalence in alternator specifications of a clause specifying the maximum divergence allowable from a true sine wave. It is however perhaps not always realized that an alternator which gives a good pressure wave on no load may give a very bad one under certain loads, and the ability of the machine to maintain a good wave form under severe conditions of load is a better criterion of its good design than is the shape of its wave at no load.

The question of wave form is of special interest to the power station engineer. Upon it depends the answer to the questions: whether he may ground his neutral wires without getting large circulating currents; whether he may safely run any combination of his alternators in parallel; whether the constants of his distributing circuit are of an order liable to cause dangerous voltage surges due to resonance with the harmonics of his pressure wave; what stresses he is getting in his insulation due to voltage surges when switching on or off, etc. It has been shown by

Rossler and Welding that the luminous efficiency of the alternating current arc may be 44 per cent. higher with a flat topped than with a peaked pressure wave, while on the other hand it is well known that transformers are more efficient on a peaked wave. Also the accuracy of many alternating current instruments depends upon the wave shape.

In making insulation breakdown tests on cables, insulators, or machinery, large errors may be introduced unless the wave form at the time of the test be known. It is not sufficient even to know that the testing alternator gives a close approximation to a sine wave at no load; since if the capacity current of the apparatus under test be moderately large compared with the full load current of the testing alternator, the charging current taken may be sufficient to distort the wave form considerably, thus giving wrong results to the disadvantage of either the manufacturer or purchaser.

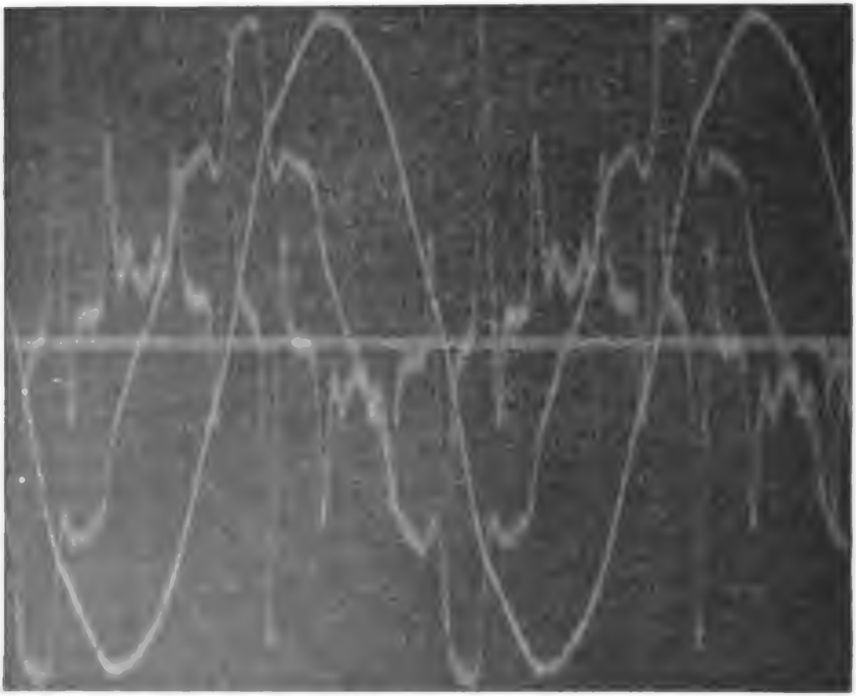


FIG 2 583 —General Electric simultaneous record of three waves with common zero.

The desirability of a complete knowledge of the manner in which the pressure and current varies during the cycle, has resulted in various methods and apparatus being devised for obtaining this knowledge. The apparatus in use for such purpose may be divided into two general classes,

1. Wave indicators;
2. Oscillographs.

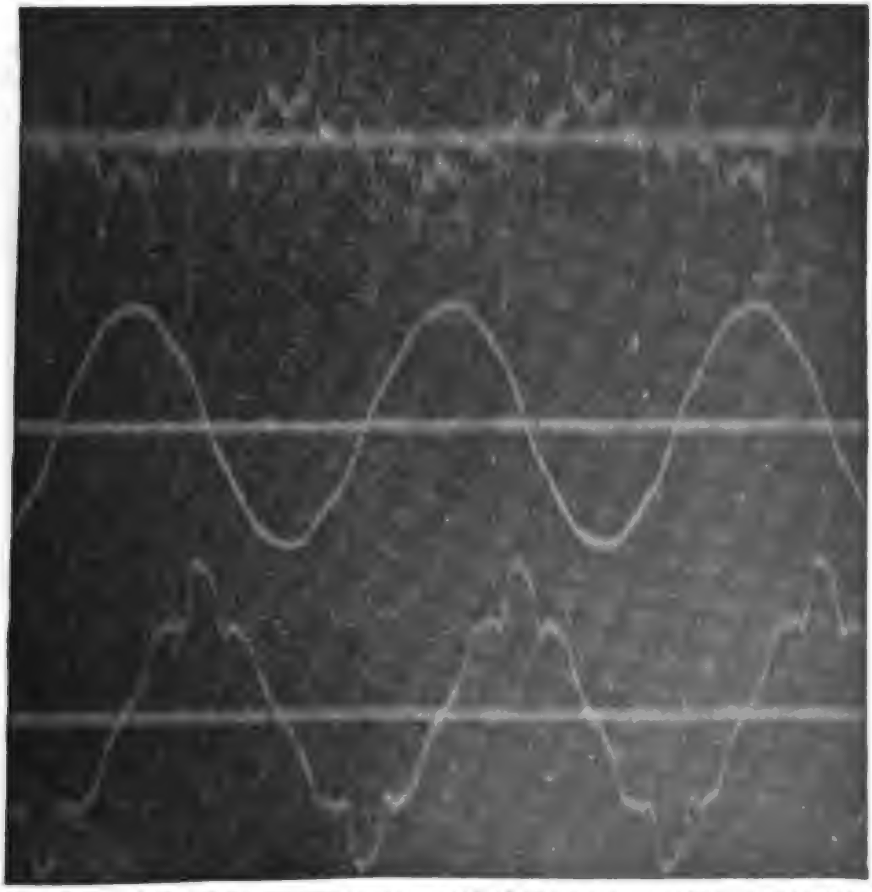
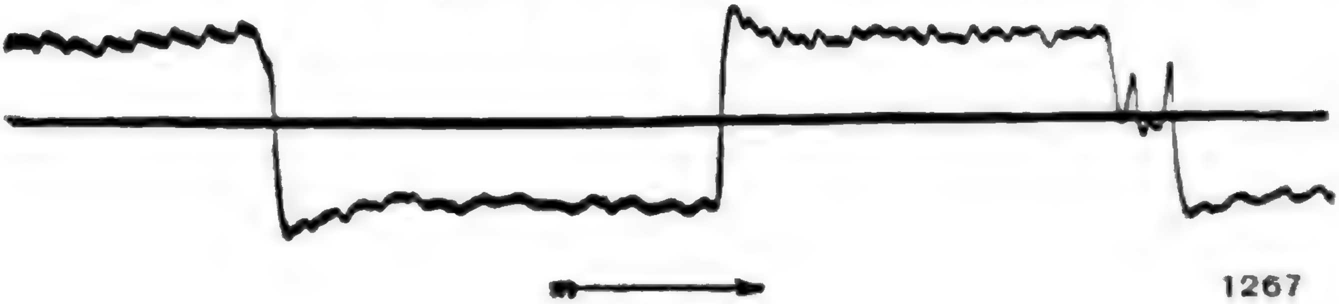


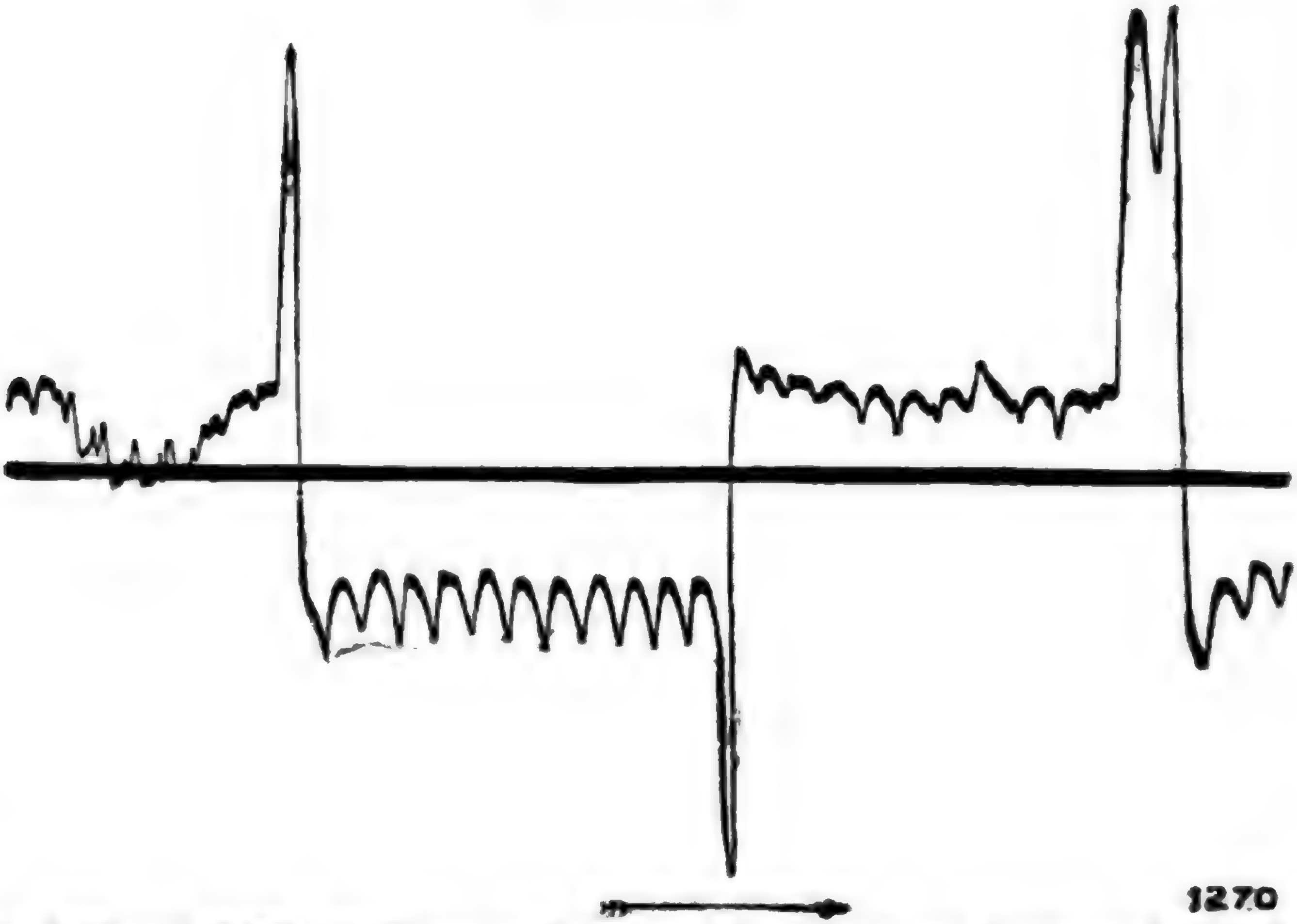
FIG. 2,584.—General Electric simultaneous record of three waves with separate zeros.

and the methods employed with these two species of apparatus may be described respectively as,

1. Step by step;
2. Constantly recording.

that is to say, in the first instance, a number of instantaneous values are obtained at various points of the cycle, which are plotted and a curve traced through the several points thus obtained. A constantly recording method is one in which an infinite number of values are determined and recorded by the machine, thus giving a complete record of the cycle, leaving no portion of the wave to be filled in.





FIGS. 2,585 and 2,586.—Oscillograms (from paper by Morris and Catterson-Smith, Proc. I. E. E., Vol. XXXIII, page 1,023), showing *how the current varies* **in one of the armature coils of a direct current motor.** Fig. 2,585 was obtained with the brushes in the neutral position, and fig. 2,586 with the brushes shifted forward.

The various methods of determining the wave form may be further classified as:

1. Step by step
   - Joubert's method;
   - Four part commutator method;
   - Modified four part commutator method;
   - Ballistic galvanometer method;
   - Zero method;
   - By Hospitalier ondograph.

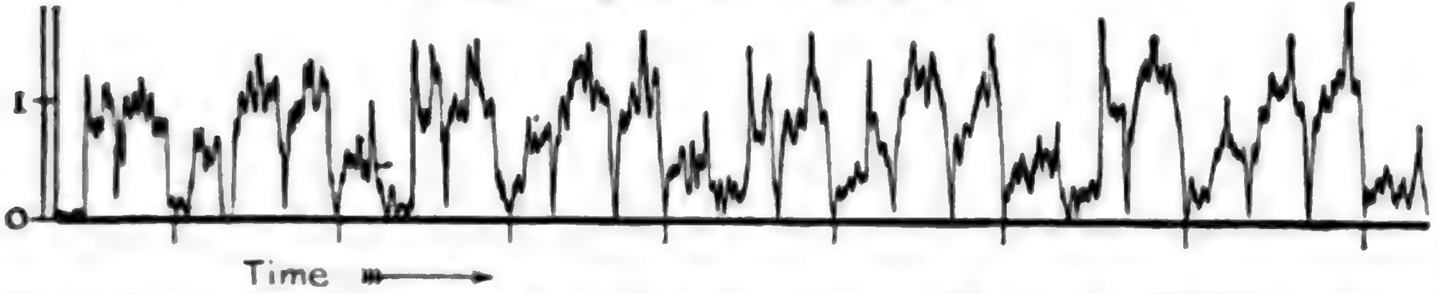


FIG. 2,587.—**Oscillogram** by Bailey and Cleghorne (Proc. I. E. E., Vol. XXXVIII), **showing** ***the sparking pressure or pressure between the brush and the commutator segment at the moment of separation.*** The waves fall into groups of three owing to the fact that there were three armature coils in each slot.

2. Constantly recording
   - by use of various types of **oscillograph,** such as
     - cathode ray;
     - glow light;
     - moving iron;
     - moving coil;
     - hot wire.

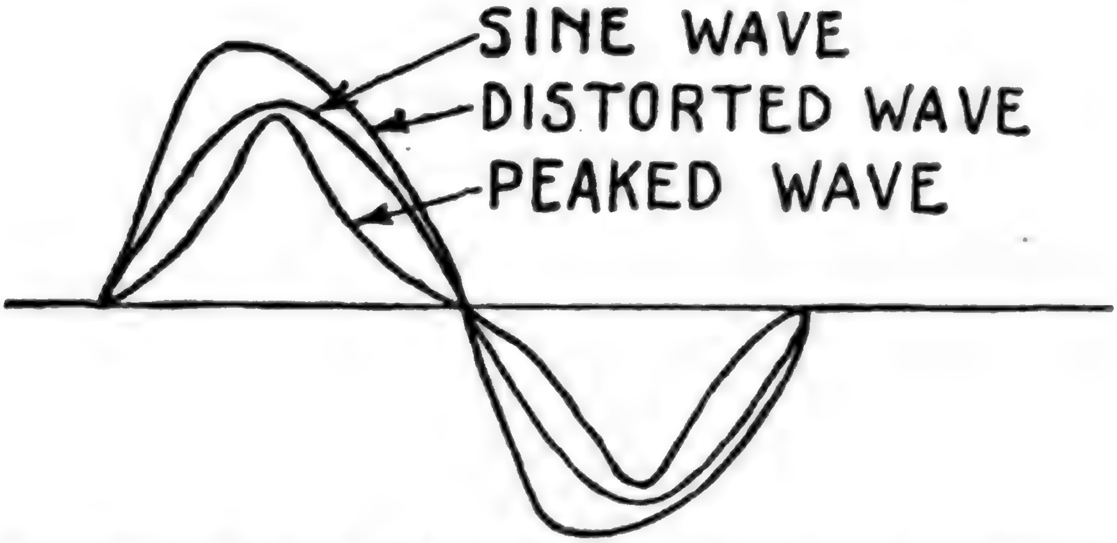


FIG. 2,588.—Various wave forms. The sine wave represents a current or pressure which varies according to the sine law. A distorted wave is due to the properties of the circuit, for instance, the effect of hysteresis in an iron core introduced into a coil is to distort the current wave by adding harmonics so that the ascending and descending portions may not be symmetrical. A peaked wave has a large maximum as compared with its virtual value. A peaked wave is produced by a machine with concentrated winding.

Joubert's Method.—The apparatus required for determining the wave form by this step by step method, consists of a galvanometer, condenser, two, two way switches, resistance and adjustable contact maker, as shown in fig. 2,589.

The contact maker is attached to the alternator shaft so that it will rotate synchronously with the latter. By means of the adjustable contact, the instant of "making" that is, of "closing" the testing circuit may be varied, and the angular position of the armature, at which the testing circuit is closed, determined from the scale, which is divided into degrees.

A resistance is placed in series with one of the alternator leads, such that the drop across it, gives sufficient pressure for testing.

Ques. Describe the method of making the test.

Ans. For current wave measurement switch No. 1 is placed on contact F, and for pressure wave measurement, on contact G, switch No. 2 is now turned to M and the drop across the resistance (assuming switch No. 1 to be turned to contact F) measured by charging the condenser, and then discharging it through the galvanometer by turning the switch to S. This is repeated for a number of positions of the contact maker, noting each time the galvanometer reading and position of the contact maker. By plotting the positions of contact maker as abscissæ, and the

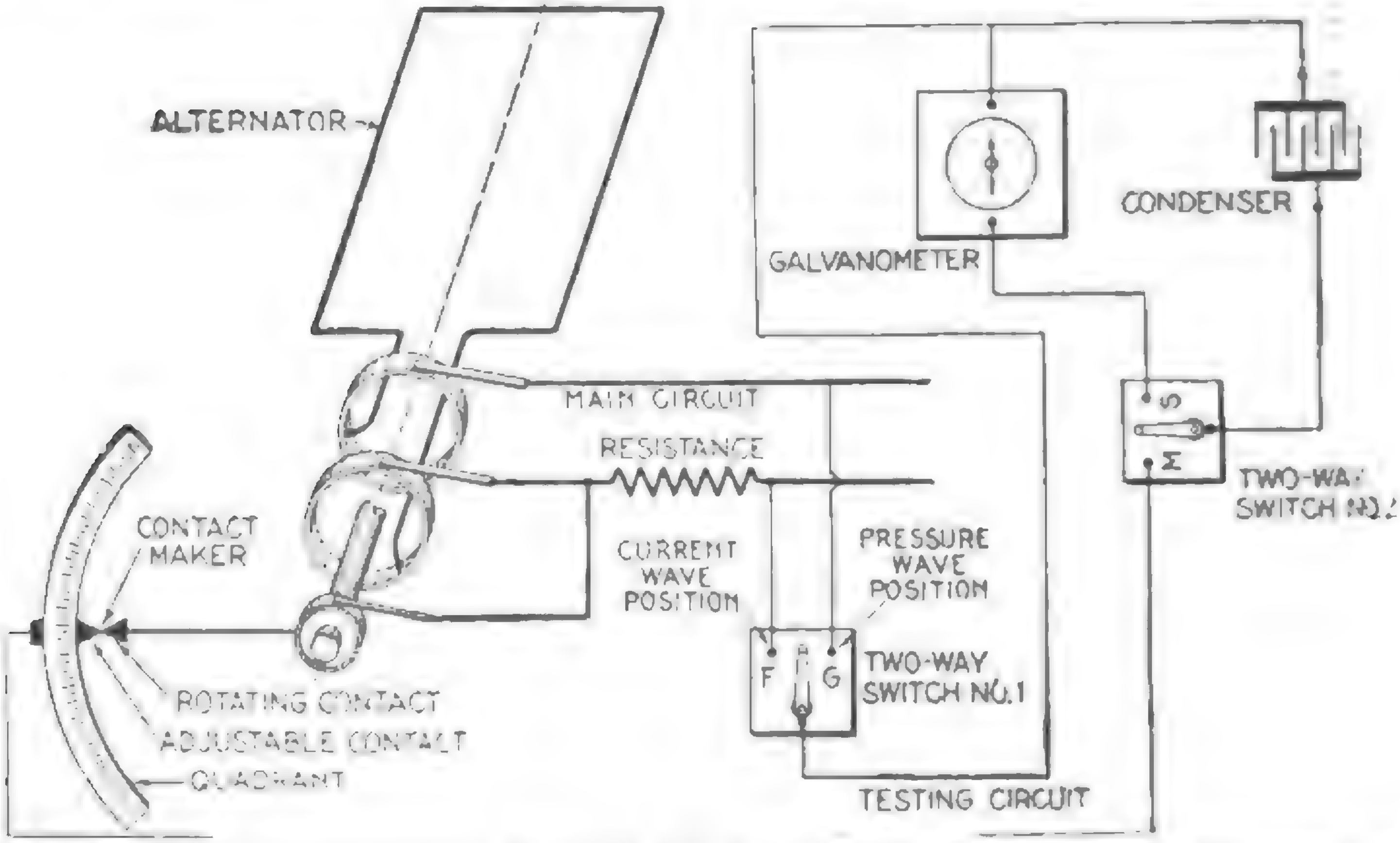

ALTERNATOR
GALVANOMETER
CONDENSER
MAIN CIRCUIT
RESISTANCE
S
M
TWO-WAY SWITCH NO.2
CONTACT MAKER
CURRENT WAVE POSITION
PRESSURE WAVE POSITION
F
G
TWO-WAY SWITCH NO.1
ROTATING CONTACT
ADJUSTABLE CONTACT
QUADRANT
TESTING CIRCUIT

FIG. 2,589.—Diagram illustrating Joubert's **step by step method of wave form measurement.**

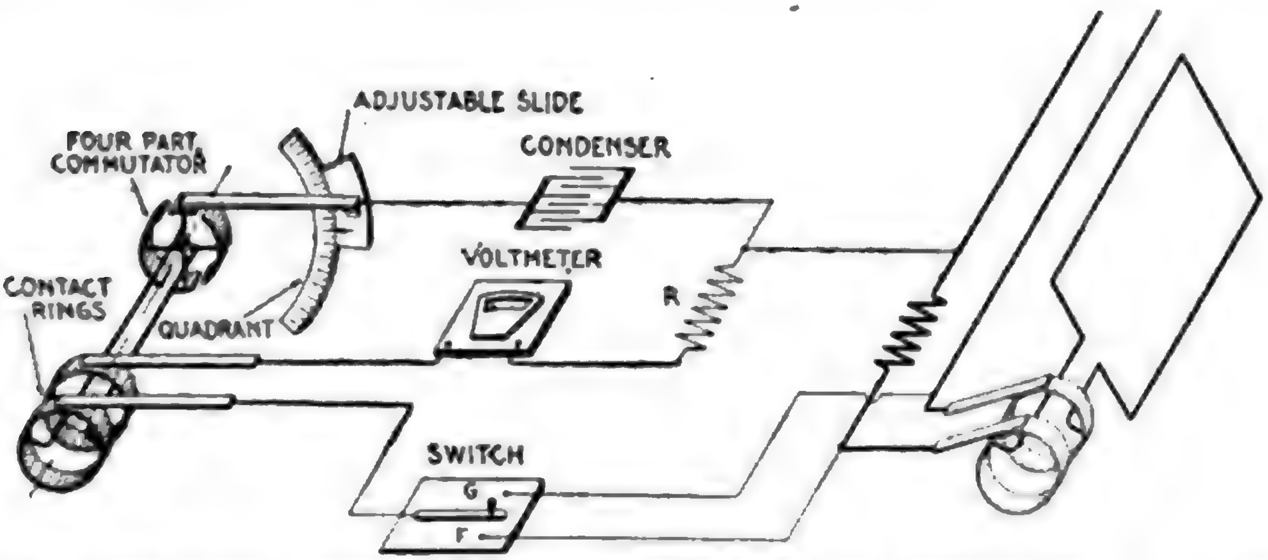

ADJUSTABLE SLIDE
FOUR PART COMMUTATOR
CONDENSER
VOLTMETER
CONTACT RINGS
QUADRANT
R
SWITCH
G
F

FIG. 2,590.—**Four part commutator method** of wave form measurement. The contact device consists of two slip rings and a four part commutator. One slip ring is connected to one terminal of the source, the other to the voltmeter, and the commutator to the condenser. By adjusting R when a known direct current pressure is impressed across the terminals, the voltmeter can be rendered direct reading.

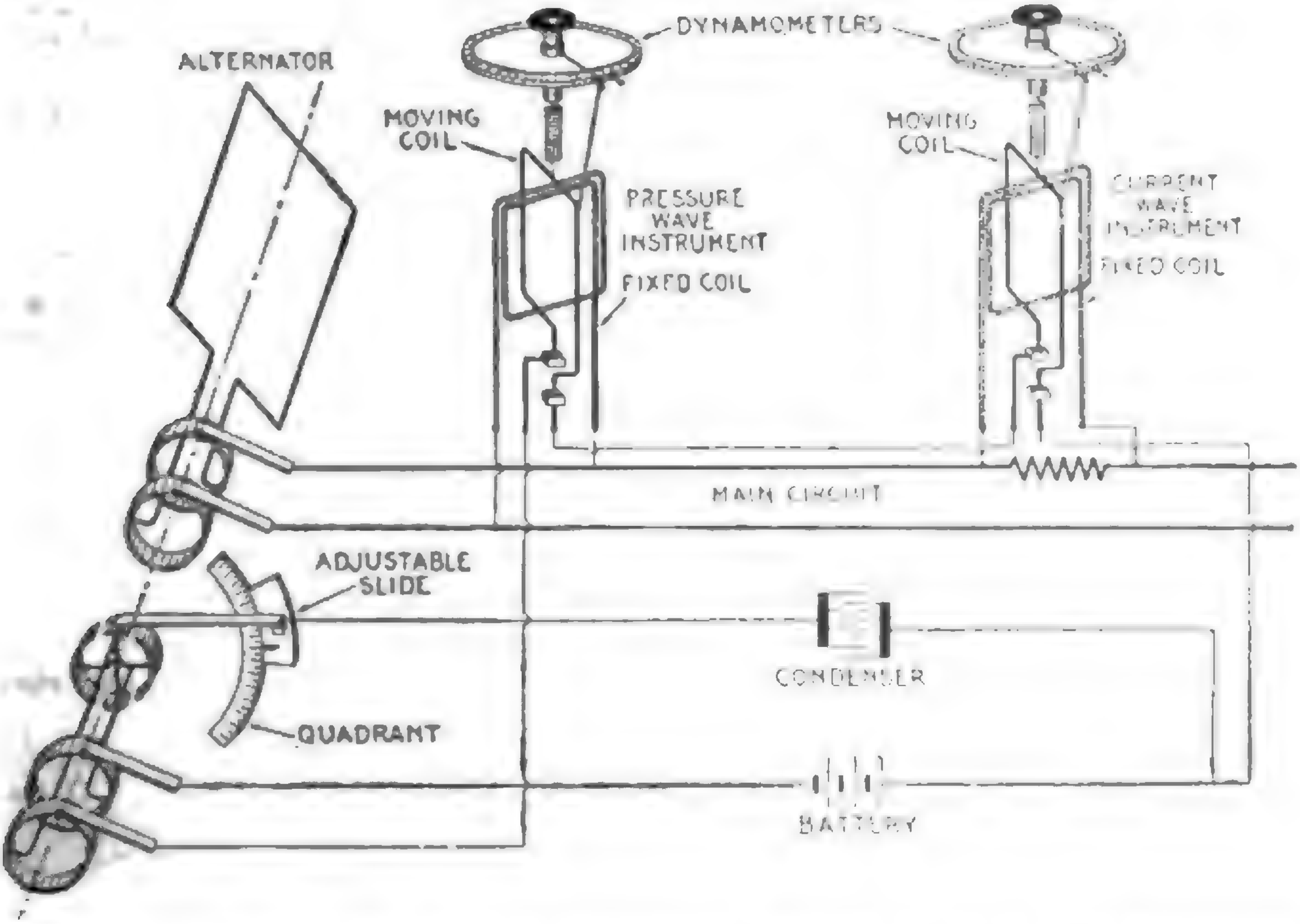

DYNAMOMETERS
ALTERNATOR
MOVING COIL
PRESSURE WAVE INSTRUMENT
FIXED COIL
MOVING COIL
CURRENT WAVE INSTRUMENT
FIXED COIL
MAIN CIRCUIT
ADJUSTABLE SLIDE
CONDENSER
QUADRANT
BATTERY

FIG. 2,591.—**Modified four part commutator method** of wave form measurement (Duncan's modification). By this method one contact maker can be used for any number of waves having the same frequency. Electro-dynamometers are used and the connections are made as here shown. The moving coils are connected in series to the contact maker, and the fixed coils are connected to the various sources to be investigated, then the deflection will be steady and by calibration with direct current can be made to read directly in volts.

galvanometer readings as ordinates, the curve drawn through them will represent the wave form.

The apparatus is calibrated by passing a known constant current through the resistance.

Ballistic Galvanometer Method.—This method, which is due to Kubber, employs a *contact breaker* instead of a *contact maker*. The distinction between these two devices should be noted: A contact maker keeps the circuit *closed* during each revolution for a short interval only, whereas, a contact breaker keeps the circuit *open* for a short interval only.

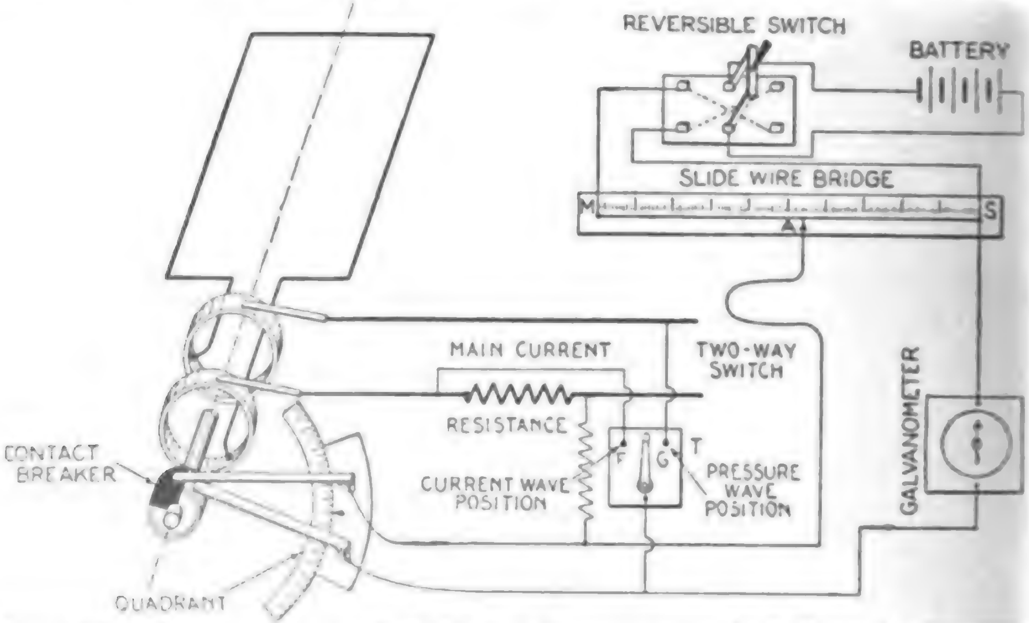

REVERSIBLE SWITCH
BATTERY
SLIDE WIRE BRIDGE
M
S
A
MAIN CURRENT
TWO-WAY SWITCH
GALVANOMETER
RESISTANCE
CONTACT BREAKER
F
G
T
CURRENT WAVE POSITION
PRESSURE WAVE POSITION
QUADRANT

FIG. 2,592.—Diagram illustrating the **ballistic galvanometer method** of wave form measurement. **The test may be made** as described in the accompanying text, or in case the contact breaker is belted instead of attached rigidly to the shaft, it could be arranged to run slightly out of synchronism, then by taking readings at regular intervals, points will be obtained along the curve without moving the contact breaker. If this method be used, a non-adjustable contact breaker suffices. **In arranging the belt drive** so as to run slightly out of synchronism, if the pulleys be of the same size, the desired result is obtained by pasting a thin strip of paper around the face of one of the pulleys thus altering the velocity ratio of the drive slightly from unity.

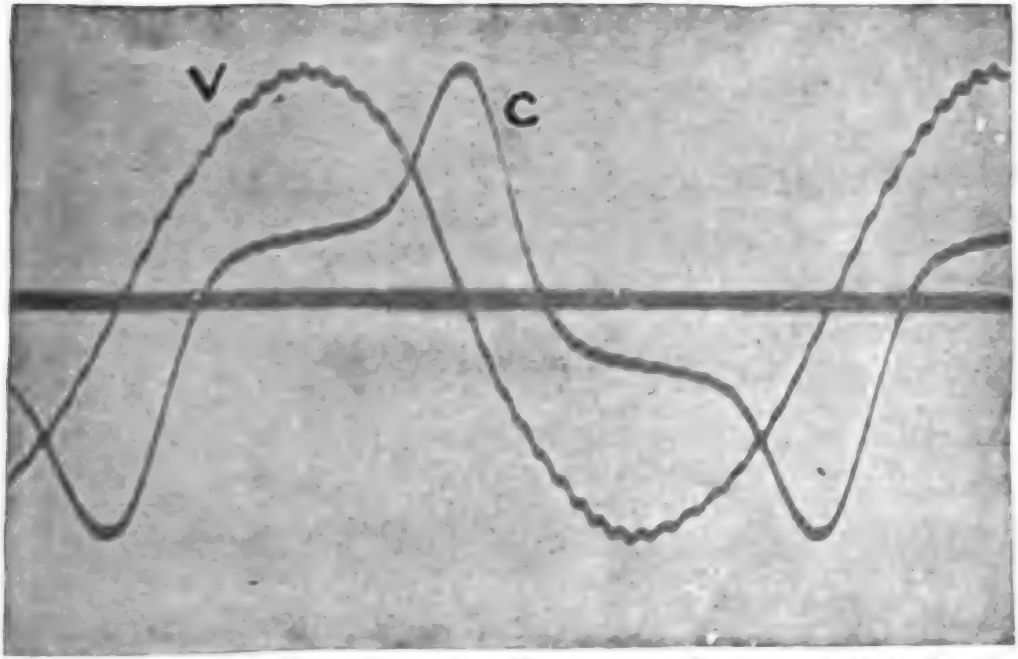
Fig. 2,592, shows the necessary apparatus and connections for applying the ballistic galvanometer method. The contact breaker consists of a commutator having an ebonite or insulating segment and two brushes.

In operation the contact breaker keeps the circuit closed during all of each revolution, except the brief interval in which the brushes pass over the ebonite segment.

The contact breaker is adjustable and has a scale enabling its various positions of adjustment to be noted.

Ques. Describe the test.

Ans. The contact breaker is placed in successive positions and galvanometer readings taken, the switch being turned to F, fig. 2,592, in measuring the current wave, and to G in measuring the pressure wave. The results thus obtained are plotted giving respectively current and pressure waves.



FIGS. 2,593 and 2,594.—**Two curves** *representing pressure and current respectively of a rotary converter.* Fig. 2,593, pressure wave V, fig. 2,594 current wave C. These waves were obtained from a converter which was being driven by an alternator by means of an independent motor. The rotary converter was supplying idle current to some unloaded transformers and the ripples clearly visible in the pressure wave V, correspond to the number of teeth in the armature of the rotary converter.

Ques. How is the apparatus calibrated?

Ans. By sending a constant current of known value through the resistance R.

Zero Method.—In electrical measurements, a zero method is one *in which the arrangement of the testing devices is such that the value of the quantity being measured is shown when the galvanometer needle points to* **zero.**

In the zero method either a contact maker or contact breaker may be used in connection with a galvanometer and slide wire bridge, as shown in figs. 2,595 and 2,596.

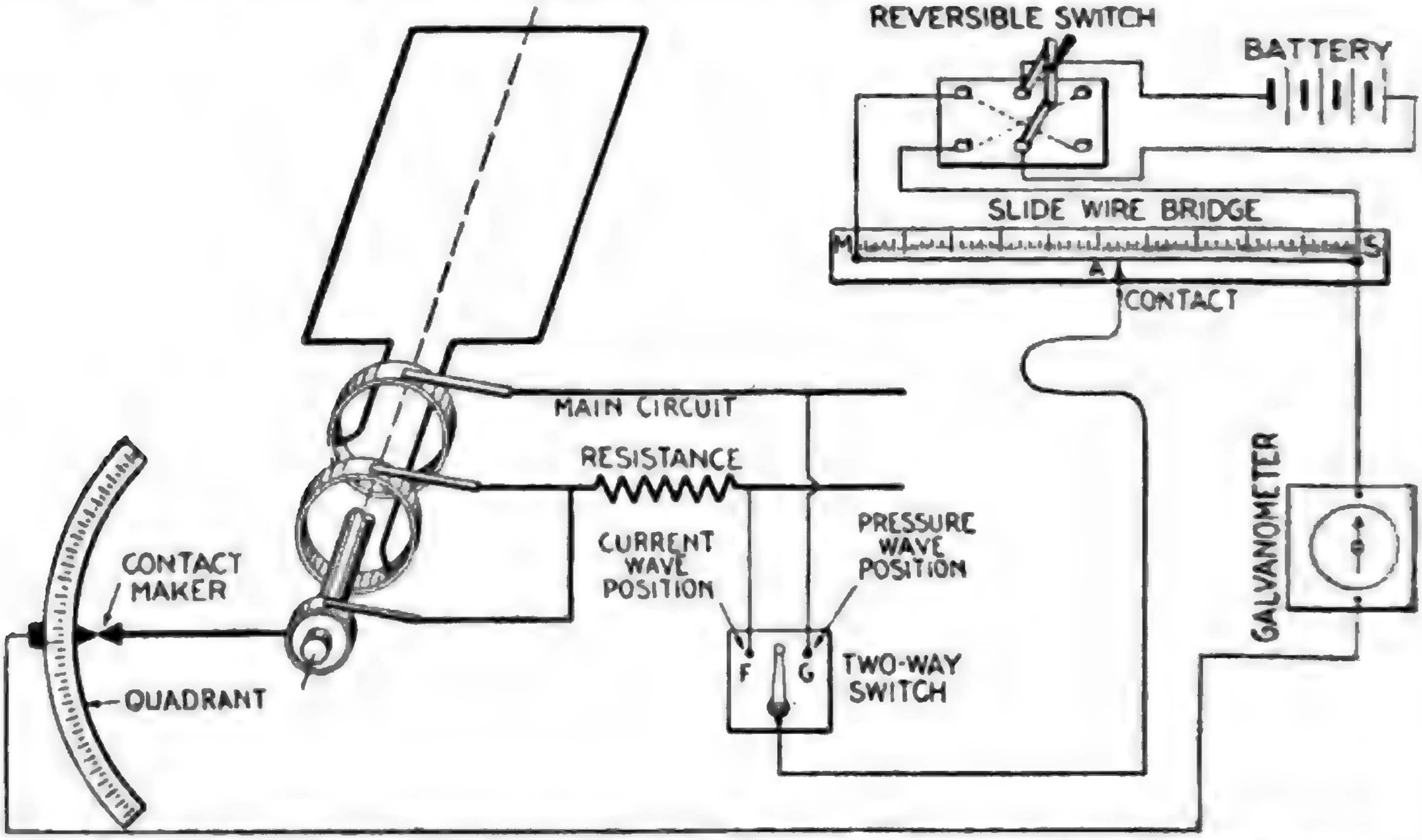

REVERSIBLE SWITCH
BATTERY
SLIDE WIRE BRIDGE
M
S
A
CONTACT
MAIN CIRCUIT
RESISTANCE
CURRENT WAVE POSITION
PRESSURE WAVE POSITION
F
G
TWO-WAY SWITCH
GALVANOMETER
CONTACT MAKER
QUADRANT

FIG. 2,595.—Diagram illustrating zero method of wave measurement with *contact* **maker.** The voltage of the battery must be at least as great as the maximum pressure to be measured and must be kept constant.

Ques. What capacity of battery should be used?

Ans. Its voltage should be as great as the maximum pressure to be measured.

Ques. What necessary condition must be maintained in the battery?

Ans. Its pressure must be kept constant.

Ques. How are instantaneous values measured?

Ans. The bridge contact A is adjusted till the galvanometer shows no deflection, then the length AS is a measure of the pressure.

The drop between these points can be directly measured with a voltmeter if desired.

Ques. How did Mershon modify the test?

Ans. He used a telephone instead of the galvanometer to determine the correct placement of the bridge contact A.

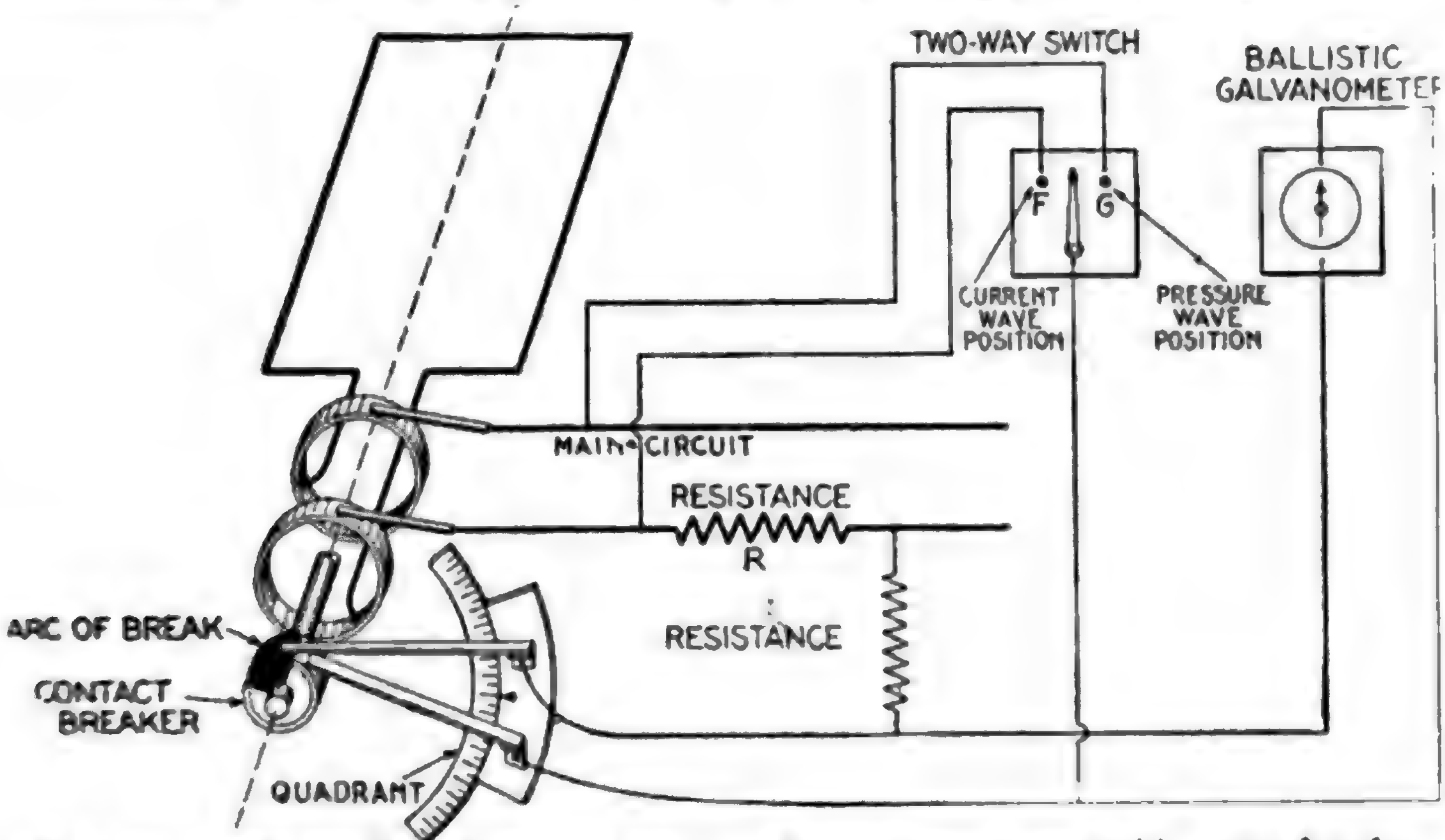

TWO-WAY SWITCH
BALLISTIC GALVANOMETER
F
G
CURRENT WAVE POSITION
PRESSURE WAVE POSITION
MAIN CIRCUIT
RESISTANCE
R
RESISTANCE
ARC OF BREAK
CONTACT BREAKER
QUADRANT

FIG. 2,596.—Diagram illustrating zero method of wave measurement with *contact* breaker. The voltage of the battery must be at least as great as the maximum pressure to be measured and must be kept constant.

Ques. How can the instantaneous values be recorded?

Ans. By attaching to the contact A, a pencil controlled by an electromagnet arranged to strike a revolving paper card at the instant of no deflection, the paper being carried on a drum.

Hospitalier Ondograph.—The device known by this name is a development of the Joubert step by step method of wave form measurement, that is to say, the principle on which its

action is based, consists in *automatically charging a condenser from each 100th wave, and discharging it through a recording galvanometer, each successive charge of the condenser being automatically taken from a point a little farther along the wave.*

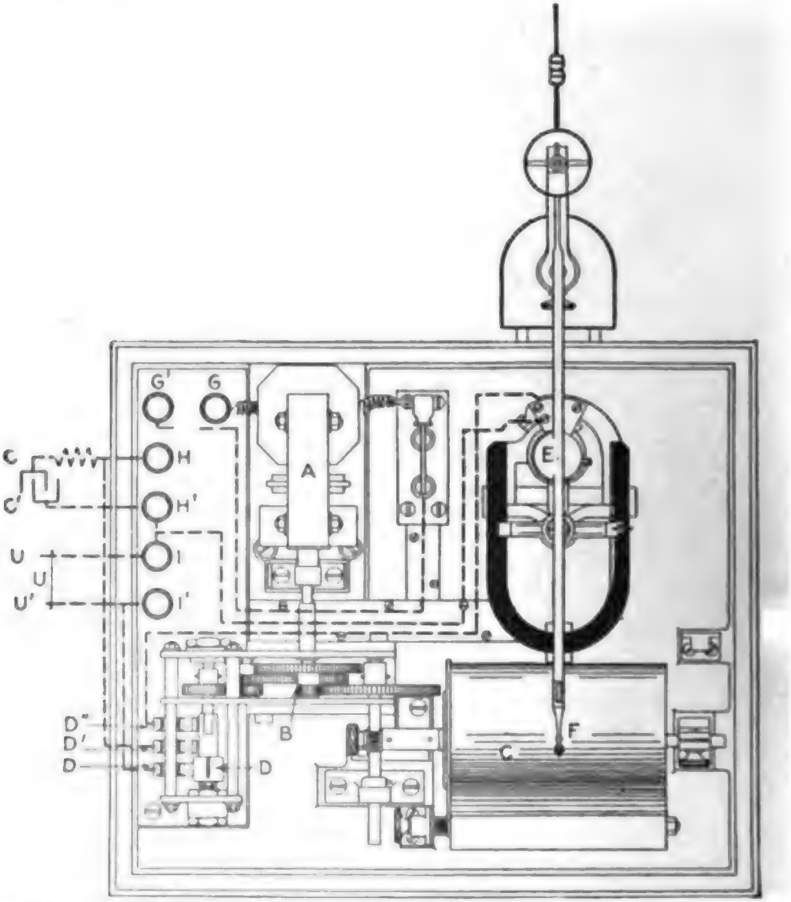


FIG. 2,597.—Diagram of Hospitalier ondograph showing mechanism and connections. It represents a development of Joubert's step by step method of wave form measurement.

As shown in the diagram, fig. 2,597, the ondograph consists of a synchronous motor A, operated from the source of the wave form to be measured, connected by gears B to a commutator D, in such a manner that while the motor makes a certain number of revolutions, the commutator makes a like number diminished by unity; that is to say, if the speed of the motor be 900 revolutions per minute, the commutator will have a speed of 899.

The commutator has three contacts, arranged to automatically charge the condenser *cc'* from the line, and discharge it through the galvanometer E, the deflection of which will be proportional to the pressure at any particular instant when contact is made.

In fig. 2,597, GG' are the motor terminals, HH' are connected to the condenser *cc'* through a resistance (to prevent sparking at the commutator) and I, I' are the connections to the service to be measured.

A permanent magnet type of recording galvanometer is employed. Its moving coil E receives the discharges of the condenser in rapid succession and turns slowly from one side to the other.

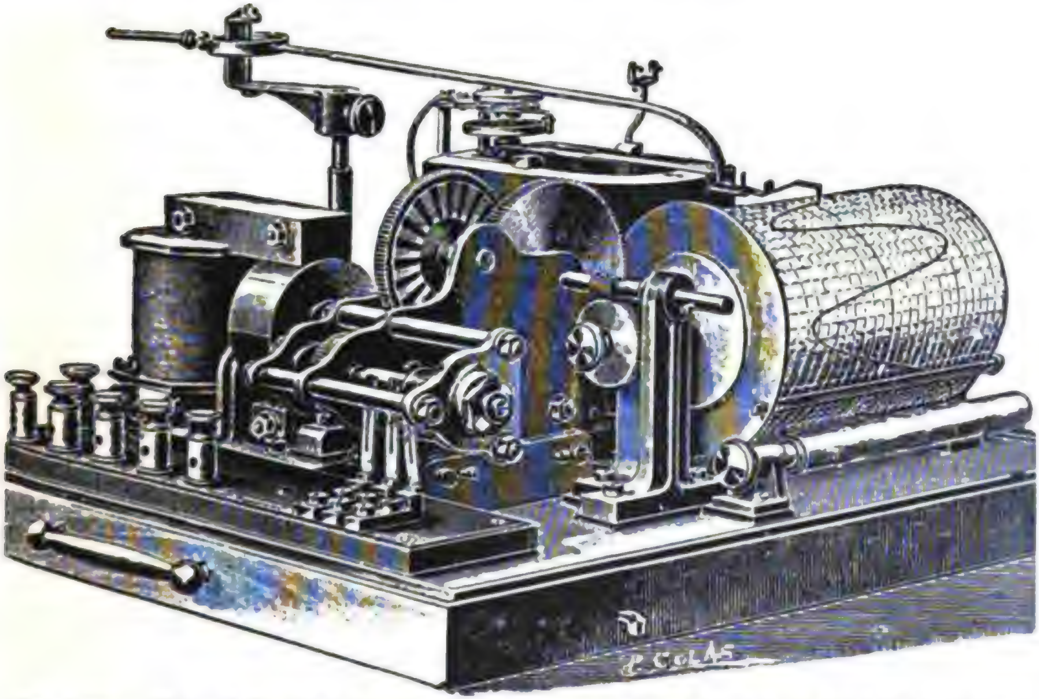


FIG. 2,598.—View of Hospitalier ondograph. **In operation,** a long pivoted pointer carrying a pen and actuated by electromagnets, records on a revolving drum a wave form representing the alternating current, pressure or current wave.

The movable part operates a long needle (separately mounted) carrying a pen F, which traces the curve on the rotating cylinder C. This cylinder is geared to the synchronous motor to run at such a speed as to register three complete waves upon its circumference.

By substituting an electromagnetic galvanometer for the permanent magnet galvanometer, and by using the magnet coils as current coils and the moving coil as the volt coil, the instrument can be made to draw watt curves. Fig. 2,598 shows the general appearance of the ondograph

Cathode Ray Oscillograph.—This type of apparatus for measuring wave form was devised by Braun, and consists of a cathode ray tube having a fluorescent screen at one end, a small diaphragm with a hole in it at its middle, and two coils of a few turns each, placed outside it at right angles to one another.

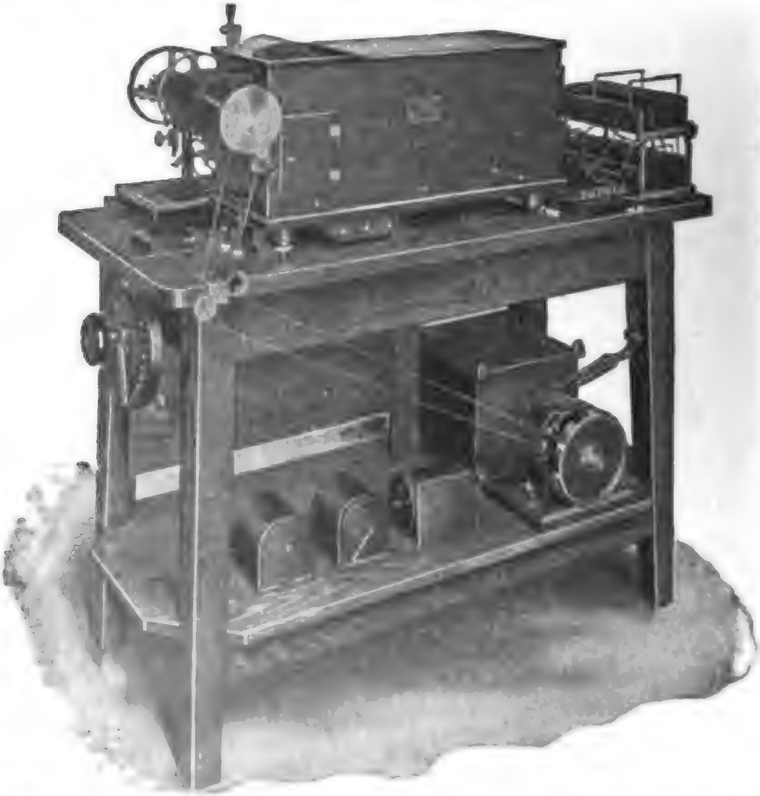


FIG. 2,599.—General Electric **moving coil oscillograph** complete **with tracing table.** The tracing table is employed for observing the waves, and by using a piece of transparent paper, the waves under observation appear as a continuous band of light which can be traced, thus making a permanent record. This is not, however, to be regarded as a recording attachment, and can not be used where instantaneous phenomena are being investigated. **The synchronous motor** for operating the synchronous mirror in connection with tracing and viewing attachment is wound for 100 to 115 volts, 25 to 125 cycles, and should, of course, be run from the same machine which furnishes power to the circuit under observation. A rheostat for steadying and adjusting the current should be connected in series with the motor. **The beam from the vibrator mirrors** *striking this synchronous mirror moves back and forth over the curved glass, and gives the length of the wave; the movement of the vibrator mirror gives the amplitude, and the combination gives the wave complete.* An arc lamp or projection lantern produces the image reflected by the mirrors upon the film, tracing table or screen. For the rotation of the photographic film, a small direct current shunt wound motor is ordinarily used.

These coils carry currents *proportional to the* **pressure** *and* **current** *respectively* of the circuit under observation.

The ray then moves so as to produce an energy diagram on the fluorescent screen.

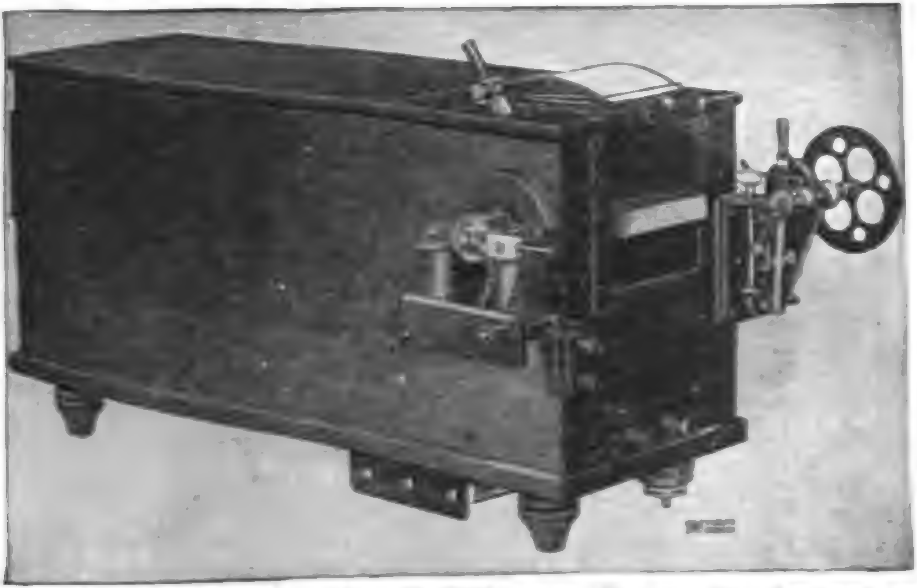


FIG. 2,600.—General Electric moving coil oscillograph. **The moving elements** *consist of single loops of flat wire carrying a small mirror and held in tension by small spiral springs.* The current passing down one side and up the other, forces one side forward and the other backward, thus causing the mirror to vibrate on a vertical axis. The vibrator elements fit into chambers between the poles of electro-magnets, and are adjustable, so as to move the beam from the mirror, both vertically and horizontally. A sensitized photographic film is wrapped around a drum and held by spring clamps. The drum, with film, is placed in a case and a cap then placed over the end, making the case light, when the index is either up or down. The loading is done in a dark room. A driving dog is screwed into the drum shaft, and which, when the drum and case are in place, revolves the film past a slot. **When an exposure is to be made,** the index is moved from the closed position, thus opening the slot in the case and exposing the film to the beam of light from the vibrating mirrors when the electrically operated shutter is open. The slot is then closed by moving the index to **"Exposed."** A slide with ground glass can be inserted in place of the film case or roll holder to arrange the optical system when making adjustments. The shutter operating mechanism is arranged so as to hold the shutter open during exactly one revolution of the film drum. There are two devices connected to the shutter operating mechanism; one opens the shutter at the instant the end of the film passes the slot; the other opens immediately, at any part of the film, and both give exposure during one revolution. The first is useful when making investigations in which the events are either recurring, or their beginnings known or under control, and the second when the time of the event is not under control, such as the blowing of fuses or opening of circuit breakers.

The instrument is much used in wireless telegraphy, as it is capable of showing the characteristics of currents of very high frequency.

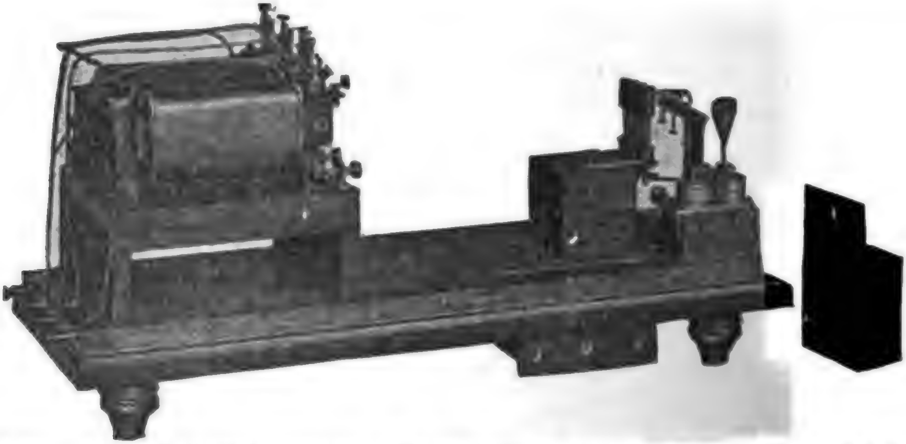


Fig. 2,601.—General Electric **moving coil oscillograph** *with case removed*, **showing** *interior construction and arrangement of parts.* The oscillograph is furnished complete with a three element electromagnet galvanometer, optical system, shutter and shutter operating mechanism, film driving motor and cone pulleys, photographic and tracing attachments, 6 film holders, and the following repair parts, for vibrators: 6 extra suspension strips; 6 vibrator mirrors: 1 box gold leaf fuses; 1 bottle mirror cement; 1 bottle damping liquid.

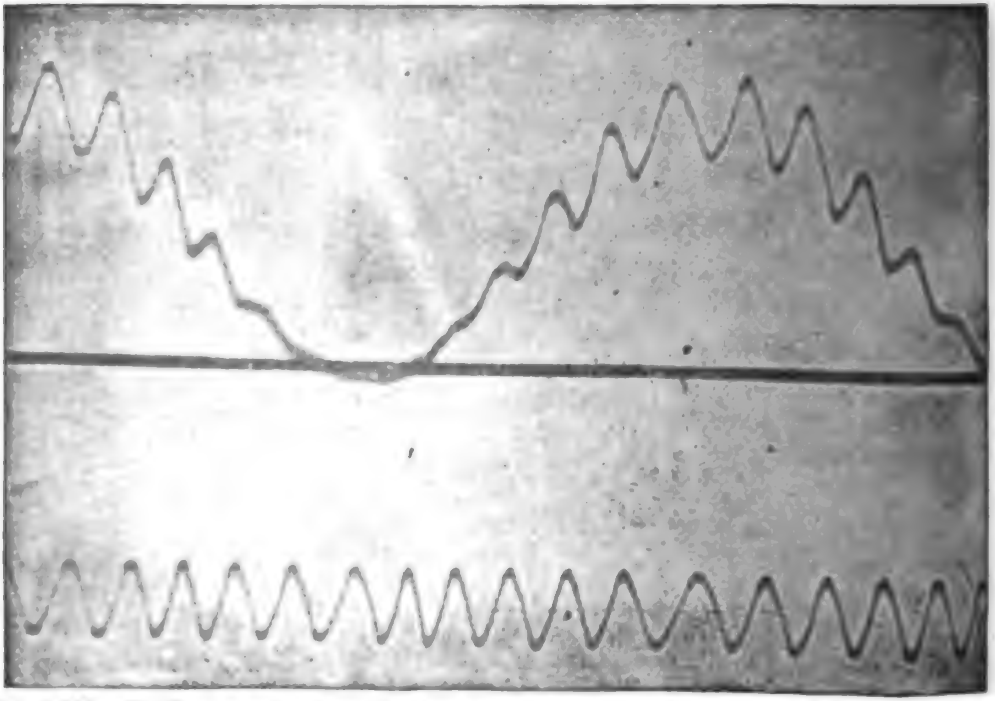


Fig. 2.602.—Oscillogram showing the direct current pressure of a 25 cycle rotary converter (below), and (above) the pressure wave taken between one collector ring and one commutator brush. The 12 ripples per cycle in the direct current voltage are due to a 13th harmonic in the alternating current supply.

Glow Light Oscillograph.—This device consists of two aluminum rods in a partially evacuated tube, their ends being about two millimeters apart. When an alternating current of any frequency passes between them a sheath of violet light forms on one of the electrodes, passing over to the other when the current reverses during each cycle. The phenomenon may be observed or photographed by means of a revolving mirror.

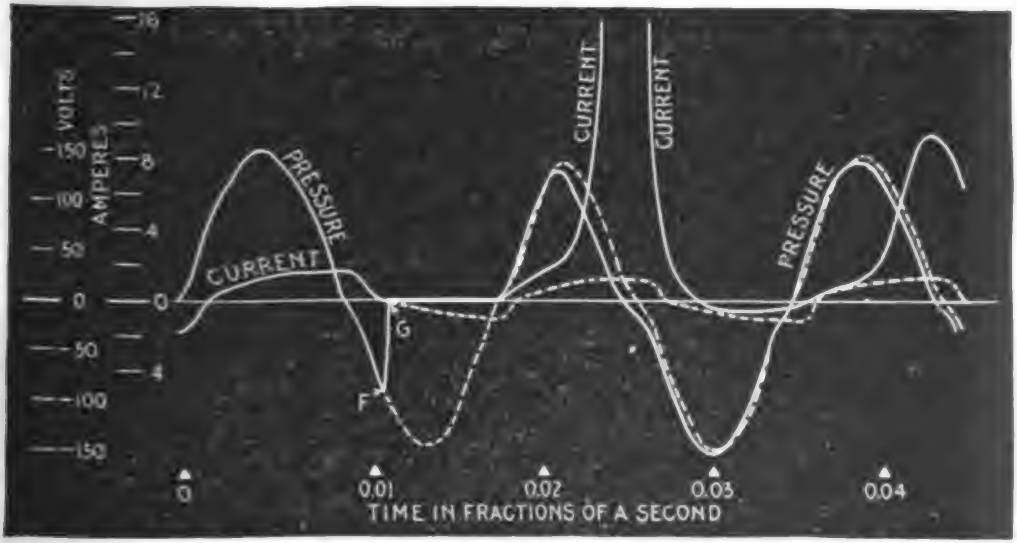


FIG. 2,603.—Curves by Morris, *illustrating the* **dangerous rush of current which may occur when switching on a transformer.** The circuit was broken at F and made again at G. The current was so great as to carry the spot of light right off the photographic plate due to the fact that a residual field was left in the core after switching off, and on closing the switch again the direction of the current was such as to tend to build up the full flux in the same direction as this residual flux. **The dotted lines** have been drawn in *to show how the actual waves were distorted from the normal.*

Moving Iron Oscillograph.—This type is due to Blondel, to whom belongs the credit of working out and describing in considerable detail the principles underlying the construction of oscillographs.

The moving iron type of oscillograph consists of a very thin vane of iron suspended in a powerful magnetic field, thus forming a polarized magnet. Near this strip are placed two small coils which carry the current whose wave form is to be measured.

The moving iron vane has a very short period of vibration and can therefore follow every variation in the current.

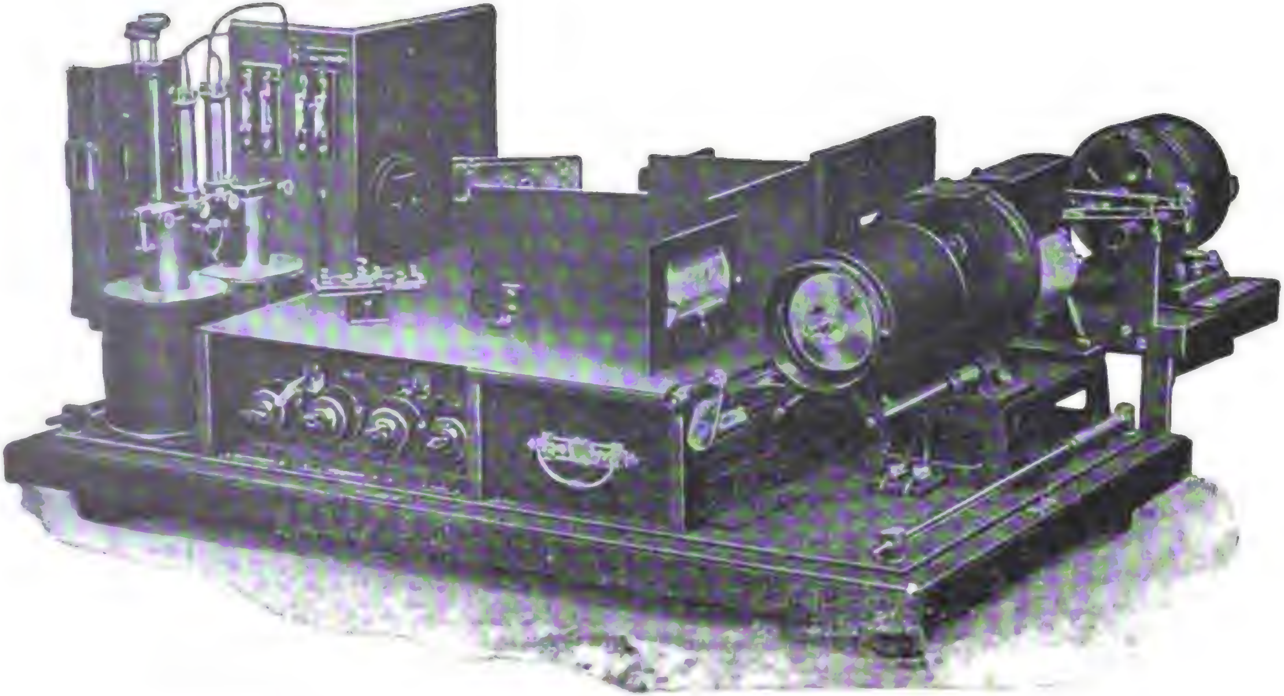
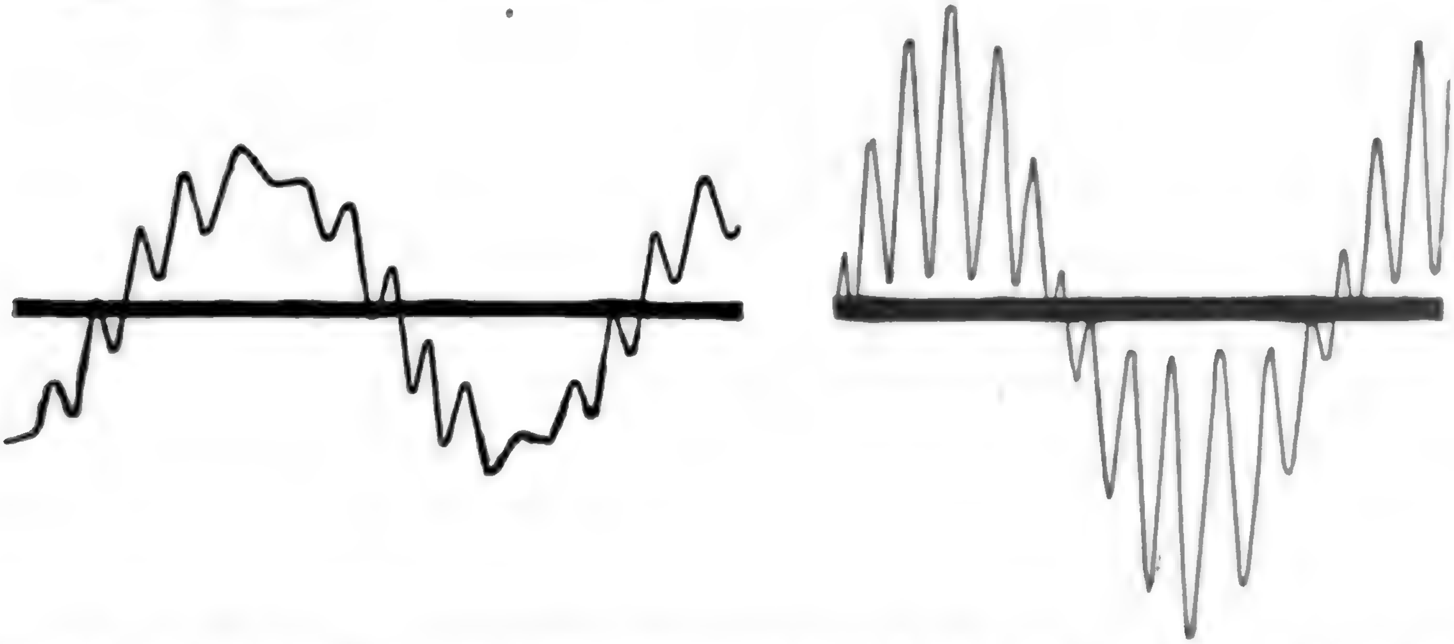


Fig. 2,604.—Siemens-Blondel **moving coil type** oscillograph. The coil is in the shape of a loop of thin wire, which is suspended in the field of an electro-magnet excited by continuous current. The current to be investigated is sent through this loop, which in consequence of the interaction of current and magnetic field, begins to vibrate. The oscillations are rendered visible by directing a beam of light from a continuous current arc lamp onto a small mirror fixed to the loop. The light reflected by the mirror is in the form of a light strip, but by suitable means this is drawn out in respect of time, so that a curve truly representing the current is obtained. The loop of fine wire is stretched between two supports and is kept in tension by a spring. As the spring tension is considerable, the directive force of the vibrating system is large, and its natural periodicity very high. The mirror is fixed in the center of the loop, and has an area of 1 square mm. In order to protect the loops from mechanical injury they are built into special frames. The mirrors are of various sizes, the loop for demonstration purposes (projection device) being provided with the largest mirror and the most sensitive loop with a mirror of the smallest dimensions.

Attached to the vane is a small mirror which reflects a beam of light upon some type of receiving device.

The Siemens-Blondel oscillograph shown in fig. 2,604, is of the *moving coil* type, being a development of the moving iron principle.

Moving Coil Oscillograph.—The operation of this form of oscillograph is based *on the behavior of a movable coil in a magnetic field.*



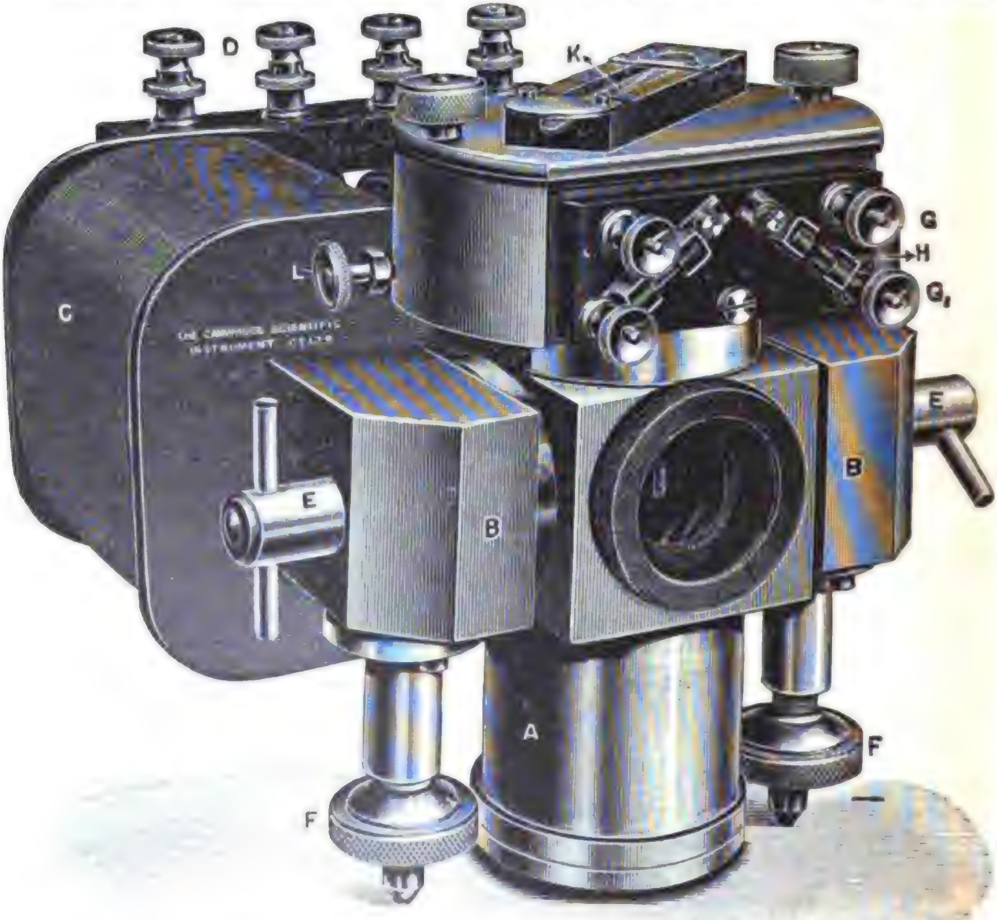
FIGS. 2,605 and 2,606.—**Oscillograms** reproduced from a paper by M. B. Field on "A Study of the **Phenomena of Resonance** by the Aid of Oscillograms" (*Journal* of *E. E.*, Vol. XXXII). **The effect of resonance** on the wave forms of alternators has been the subject of much investigation and discussion; it is a matter of vital importance to the engineer in charge of a large alternating current power distribution system. Fig. 2,605 shows the pressure curve of an alternator running on a length of unloaded cable, the 11th harmonic being very prominent. Fig. 2,606 shows the striking alteration produced by reducing the length of cable in the circuit and thus causing resonance with the 13th harmonic.

It consists essentially of a modified moving coil galvanometer combined with a rotating or vibrating mirror, a moving photographic film, or a falling photographic plate. The galvanometer portion of the outfit is usually referred to as the oscillograph as illustrated in figs. 2,608 to 2,612, representing diagrammatically the moving system.

In the narrow gap between the poles S, S of a powerful magnet are stretched two parallel conductors formed by bending a thin strip of phosphor bronze back on itself over an ivory pulley P. A spiral spring attached to this pulley serves to keep a uniform tension on the strips, and a guide piece L limits the length of the vibrating portion to the part actually in the magnetic field.

A small mirror M bridges across the two strips as shown. The effect of passing a current through such a "vibrator" is to cause one of the strips to advance while the other recedes, and the mirror is thus turned about a vertical axis.

Each strip of the loop passes through a separate gap (not shown in the figure). The whole of the "vibrator," as this part of the instrument is called, is immersed in an oil bath, the object of the oil being to damp


D
K
G
H
G_1
L
C
THE CAMBRIDGE SCIENTIFIC INSTRUMENT CO LTD
E
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B
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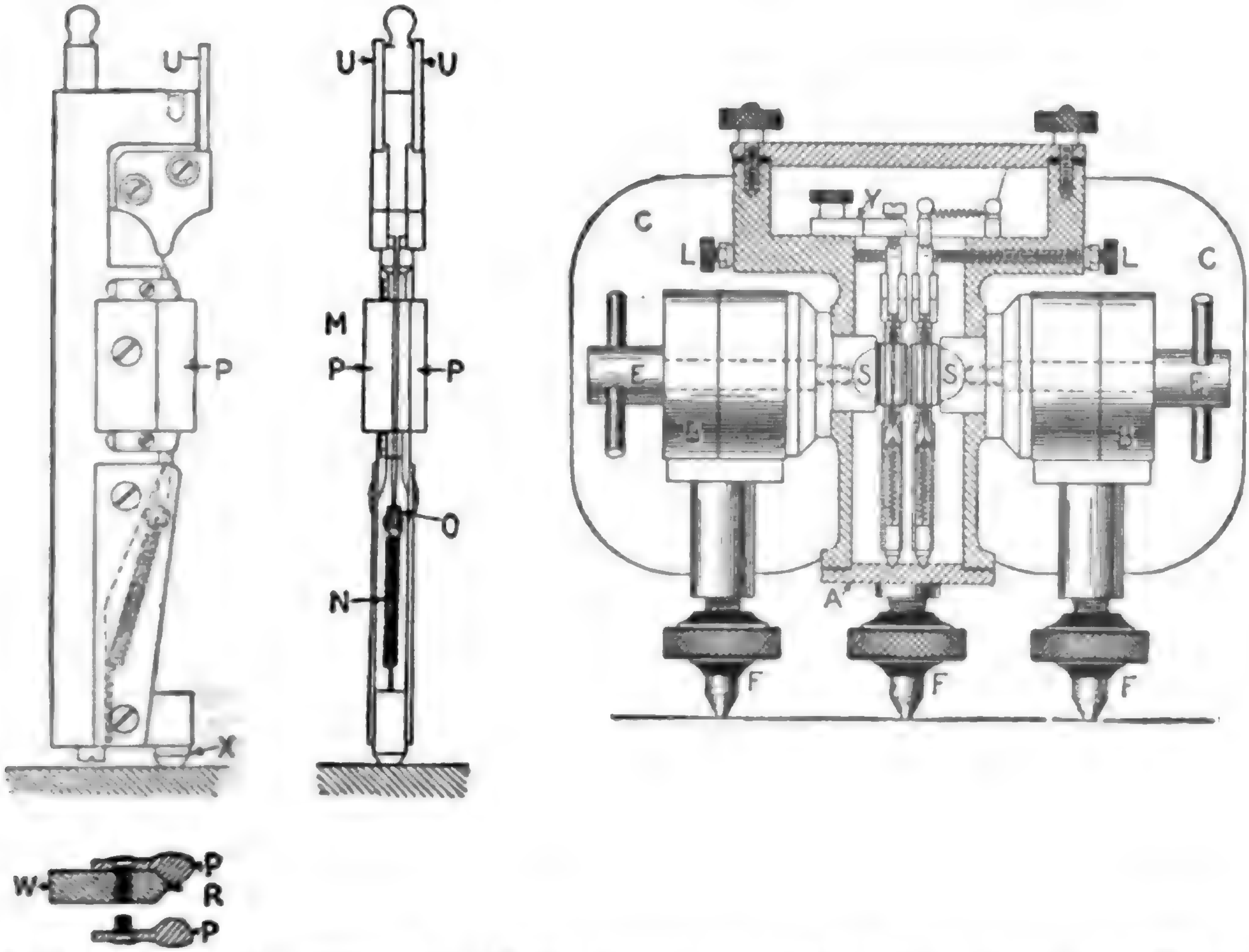
F

FIG. 2,607.—General view of electro-magnet form of Duddell moving coil oscillograph, showing oil bath and electro-magnet. This instrument is specially designed to have a very high natural period of vibration (about $\frac{1}{10{,}000}$ of a second) so as to be suitable for accurate research work. It is quite accurate for frequencies up to 300 per second. In the figure, A is the brass oil bath in which two vibrators are fixed; B, core of electro-magnet which is excited by two coils, one of which, C, is seen. The ends of these two coils are brought out to four terminals at D, so that the coils may be connected in series for 200 volt, or in parallel for 100 volt circuits. The bolts, E,E, hold the oil bath in position between the poles of the magnet. F,F,F (one not seen), are levelling screws; G,G, terminals of one vibrator; H, fuse; K, thermometer with bulb in center of oil bath.



FIGS. 2,608 to 2,612.—**Vibrator** of Duddell moving coil oscillograph and **section through oil bath** of electromagnet oscillograph. **The vibrator consists of** a brass frame W, which supports two soft iron pole pieces P,P. Between these, a long narrow groove is divided into two parts by a thin soft iron partition, which runs up the center. The current being led in by the brass wire U, passes from an insulated brass plate to the strip, which is led over an ivory guide block, down one of the narrow grooves and over another guide block, the loops round the ivory pulley O, which puts tension on the strip by the spring N, back to the guide block again, up the other narrow groove, and out by way of the insulated brass plate and lead U. Halfway up the grooves the center iron partition R is partially cut away to permit of a small mirror M, bridging across from one strip to the other, being stuck to the strips by a dot of shellac at each corner. The figure illustrates one type of vibrator in which P is removable from W for ease in repairing. In type 1, these pole pieces P,P are not removable. **The vibrators** are placed side by side in the gap between the poles S,S of the electromagnet, see fig. 2,610. Each vibrator is pivoted about vertical centers, the bottom center fitting in the base of the oil bath, and the one at the top being formed by a screw in the cock piece Y. It can thus be easily turned in azimuth, its position being fixed by the adjusting screw L, a spiral spring serving to keep the vibrator always in contact with this screw. Since each cock piece can be independently moved forward or backward, each vibrator can be tipped slightly in either of these directions so that complete control over the mirrors is obtained and reflected spots of light may be made to coincide with that reflected from the fixed zero mirror, which latter is fixed to a brass tongue in between the two vibrators. **A plano-convex lens** of 50 cm. focal length is fixed on the oil bath in front of the vibrator mirrors to converge the reflected beams of light. It will be noticed that this lens is slightly inclined so that no trouble will be given by reflections from its own surface. The normal distance from the vibrator mirrors to the scale of photographic plate is 50 cm., and at this distance, a convenient working deflection on each side of the zero line is 3 to 4cm. This is obtained with a R.M.S. current through the strips of from .05 to .1 of an ampere according to wave form, etc. **The maximum deflection** on each side of the zero line should not exceed 5cm. while the maximum R.M.S. current through the strips should in no case exceed .1 ampere.

the movement of the strips, and make the instrument dead beat. It also has the additional advantage of increasing by refraction the movement of the spot of light reflected from the vibrating mirrors.

The beam of light reflected from the mirror M is received on a screen or photographic plate, the instantaneous value of the current being proportional to the linear displacement of the spot of light so formed.

With alternating currents, the spot of light oscillates to and fro as the current varies and would thus trace a straight line.

To obtain an image of the wave form, it is necessary to traverse the photographic plate or film in a direction at right angles to the direction of the movement of the spot of light.

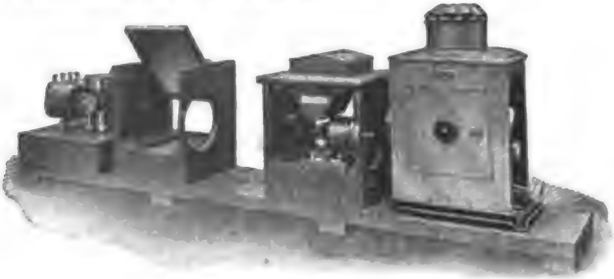
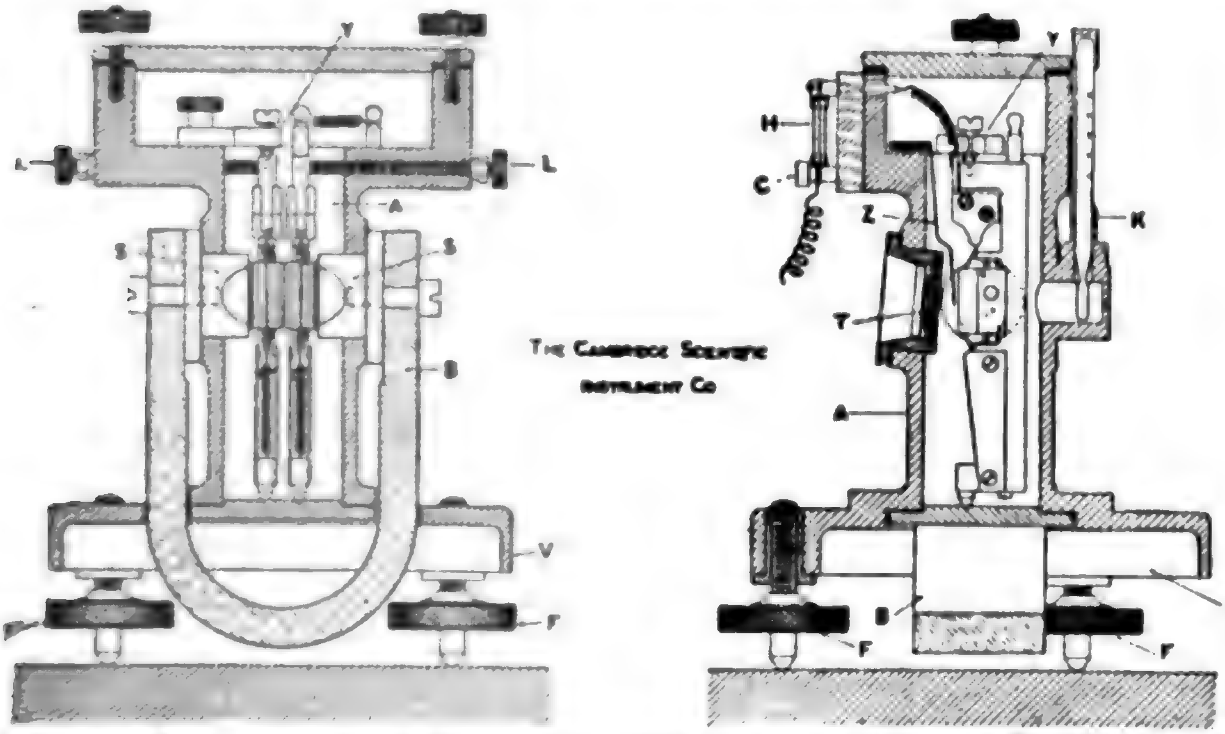


FIG. 2,613.—**Duddell moving coil oscillograph** *with projection and tracing desk outfit.* The outfit is designed for teaching and lecture purposes. **In operation,** *after the beam of light from the arc lamp has been reflected from the oscillograph mirrors, it falls on a vibrating mirror which gives it a deflection proportional to time in a direction at right angles to the deflection it already has and which is proportional to the current passing through the oscillograph.* It is therefore only necessary to place a screen in the path of the reflected beam of light to obtain a trace of the wave form. Since the vibrating mirror is vibrated by means of a cam on the shaft of a synchronous motor, which motor is driven from, or synchronously with, the source of supply whose wave form is being investigated, the wave form is repeated time after time in the same place on the screen, and owing to the "persistence" of vision, the whole wave appears stationary on the screen. The synchronous motor with its vibrating mirror, mentioned above, is located underneath the "tracing desk." When used in this position a wave a few centimeters in amplitude is seen through a sheet of tracing paper which is bent round a curved sheet of glass. A permanent record of the wave form can thus easily be traced on the paper. A *dark box* which is designed to hold a sheet of sensitized paper in place of the tracing paper, can be fitted in place of the tracing desk. Thus an actual photographic record of the wave form is obtained. If the synchronous motor be transferred from its position underneath the tracing desk to the space reserved for it close to the oscillograph, the beam of light is then received on a large mirror which is placed at an angle of about 45 degrees to the horizontal and so projects the wave form onto a large vertical screen which should be fixed about two and a half meters distant. Under these conditions a wave form of amplitude 50 cm. each side the zero line may be obtained which is therefore visible to a large audience.

Ques. How are the oscillograms obtained in the Duddell moving coil oscillograph?

Ans. In all cases the oscillograms are obtained by a spot of light tracing out the curve connecting current or voltage with time. The source of light is an arc lamp, the light from which passes first through a lens, and then, excepting when projecting on a screen, through a rectangular slit about 10 mm. long by 1 mm. wide. The position of the lamp from the lens is adjusted till an image of the arc is obtained covering the three (two moving, one fixed) small oscillograph mirrors. The light is reflected back from these mirrors and, being condensed by a lens which is immediately in front of them, it converges till an image of the slit is formed on the surface where the record is desired. All that is necessary now to obtain a bright spot of light instead of this line image is to introduce in the path of the beam of light a cylindrical lens of short focal length.



FIGS. 2,614 and 2,615.—Sectional view of **permanent magnet form** of Duddell **moving coil oscillograph.** This instrument has a lower natural period of vibration ($\frac{1}{3,000}$ second) than the type shown in fig. 2,612, and therefore is not capable of accurately following wave forms of such high frequency, but it is sufficiently quick acting to follow wave forms of all ordinary frequencies with perfect accuracy. It is easier to repair, and more portable, owing to the fact that the magnetic field is produced by a permanent magnet instead of an electro-magnet. This also renders the instrument suitable for use on high tension circuits without earth connection, as, owing to the fact that no direct current excitation is required, the instrument is more easily insulated than other types.

Ques. What is the function of the mirrors on the vibrating vane?

Ans. They simply control the direction of a beam of light

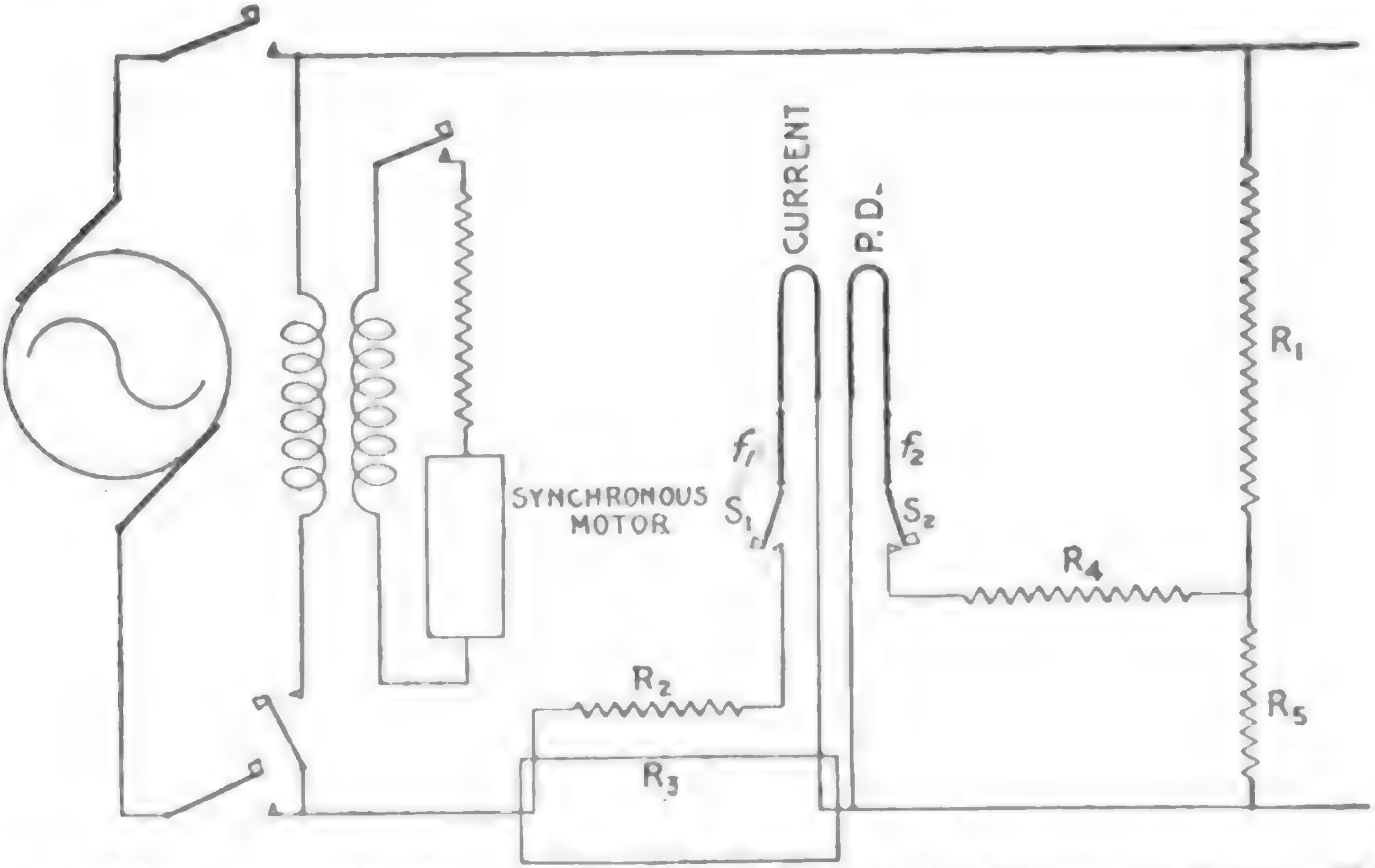


FIG. 2,616.—Diagram of connections of Duddell oscillograph **to high pressure circuit.** The modification necessary for high pressure circuit only applies to the vibrator which gives the pressure wave and consists in adding two more resistances, R_4 and R_5. Referring to fig. 2,617, it will be seen that in case fuse f_2 blow, or the vibrator be accidentally broken, the full supply voltage is immediately thrown on the instrument itself. This is not permissible in high voltage work and therefore the resistance R_5 is introduced as a permanent shunt to the oscillograph vibrator. The resistance R_4 is an exact duplicate of R_2, being a 21 ohm plug resistance box for adjusting the sensitivity of the vibrator to an even figure. **In practice** R_5 is usually a part of R_1, and in most of the high voltage resistances, two taps are brought out near one end to serve as R_5. One of these taps is usually 50 ohms distant from the end terminal and the other only 5 ohms from the end. **The use of these taps is as follows:** The large resistance consisting of $R_1 + R_5$ is so chosen with respect to the voltage of the circuit under investigation that the current through R_1 is about .1 ampere. *It should never be more than this continuously.* Then R_4 is connected to the 50 ohm tap, and since the resistance of the oscillograph vibrator circuit is variable from about 5 to 26 ohms by means of R_4, the current can be controlled through the oscillograph from about .066 to .091 of an ampere, enabling an open wave form to a convenient scale to be obtained. **If it now be desired to record large rises of pressure,** such as may occur in cases of resonance, *the height of the wave must be reduced in order to keep these rises on the plate.* This is accomplished by disconnecting R_4 from the 50 ohm tap and connecting it to the 5 ohm tap, when the current through the vibrator will be from .05 to .016 of an ampere according to whether the resistance R_4 is in or out of circuit. When, instead of using the *falling plate*, the *continuous film* camera is being used, it becomes necessary always to work on the 5 ohm tap since the width of the film is much less than that of the plate, and the current must therefore be less. **In experiments where sudden rises of voltage are expected** *it is often advisable to keep R_1 as great as possible.* That end of the resistance R_1 referred to as R in the diagram should be directly connected to the supply main and no switch or fuse used. A switch may, if desired, be used in series with R_1, provided it be inserted at the point where R_1 joins the supply main remote from R_5. It will be seen that fuses f_1 and f_2 are shown. Provided that the connections are always made in accordance with the diagram, and the vibrators are always shunted by R_3 or R_5 respectively, there is not much objection to the use of these fuses, but on general principles it is wise to avoid fuses in high tension work and accordingly with each permanent magnet oscillograph, dummy fuses are supplied which can be inserted in place of the ordinary fuses when desired. *The remark previously made about keeping both vibrators and the frame of the instrument at approximately the same pressure applies with additional emphasis in high pressure work.*

in a horizontal plane in such a manner that its deflection from a zero position depends on the current passing through the instrument, and it is therefore evident that the oscillograph is not complete without means of producing a time scale.

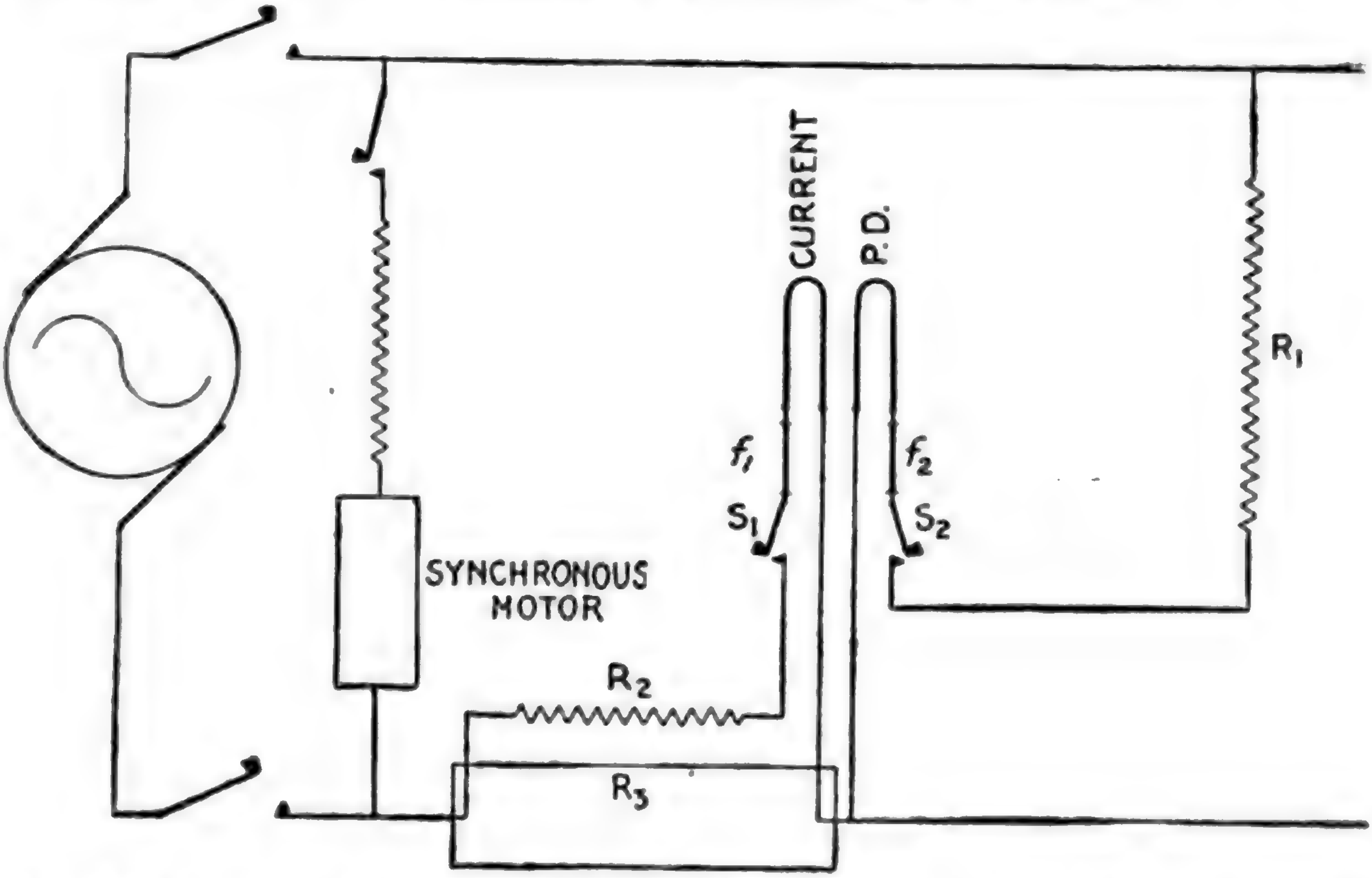
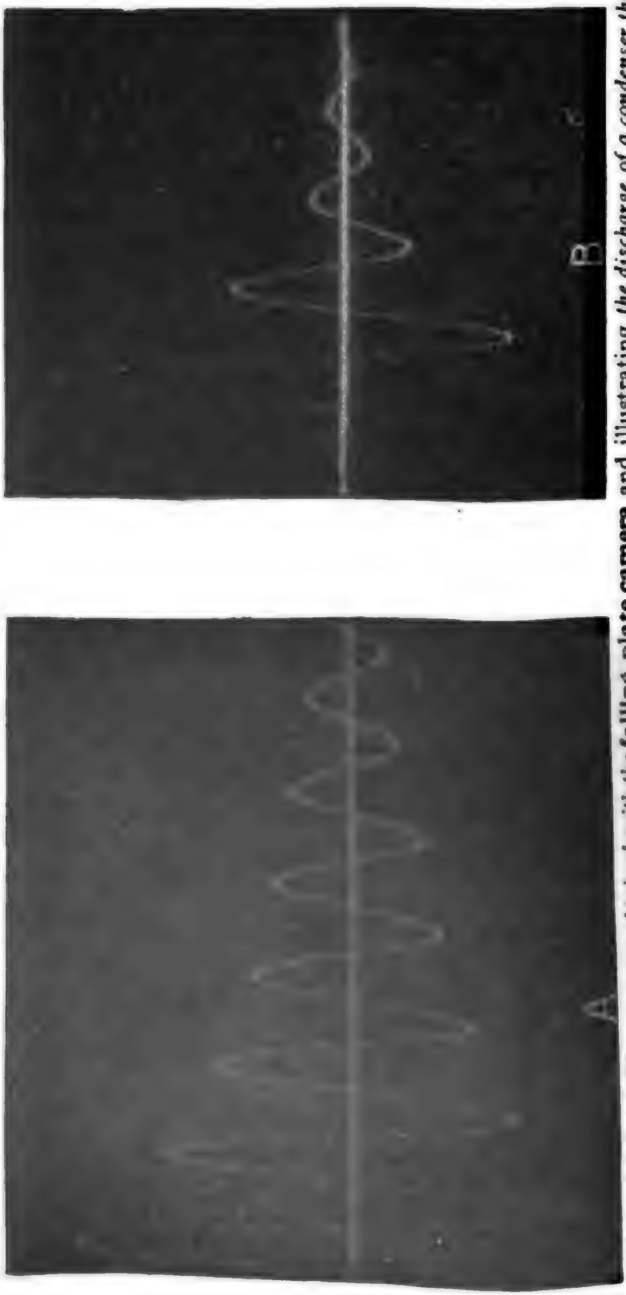


FIG. 2,617.—Diagram of connections of Duddell oscillograph **to low pressure circuit,** R_1 is a high non-inductive resistance connected across the mains in series with one of the vibrators. S_2 is a switch, and f_2, the fuse (on the oscillograph in this circuit). The resistance of R_1 in ohms should be rather more than ten times the voltage of the circuit, so that a current of a little less than .1 of an ampere will pass through it. The vibrator will then give the curve of the circuit on an open scale. (For the projection oscillograph, the resistance R_1 should be only twice the supply voltage, since .5 of an ampere is required to give full scale deflection on a large screen.) **To obtain the current wave form,** *the shunt R_3 is connected in series with the circuit under investigation and the second vibrator is connected across this shunt.* Here also f_1 is a fuse, S_1 a switch, and R_2 an adjustable resistance box. The switch S_1 is however unnecessary if the plug resistance box supplied for R_2 be used, since an infinity plug is included in this box. The shunt R_3 should have a drop of about 1 volt across it in order to give a suitable working current through the vibrator. The resistance R_2 is not absolutely essential, but it is a great convenience in adjusting the current through the vibrator. It is a plug resistance box, the smallest coil being .01 of an ohm and the total 21 ohms. Being designed to carry .5 ampere continuously it can be used with any other type of Duddell oscillograph, and by its use the sensitiveness of the vibrator can be adjusted so that a round number of amperes in the shunt gives 1 mm. deflection. This adjustment is best made with direct current. **It should be noted** in connecting the oscillograph in circuit, that *the two vibrators should be so connected to the circuit that it is impossible that a higher pressure difference than 50 volts should exist between one vibrator and the other, or between either vibrator and the frame.* To ensure attention to this important point, a brass strap is provided which connects the two vibrators together and to the frame of the instrument. This does not mean that this point must necessarily be earthed since the frame of the instrument is insulated from the earth. It is advisable, however, to earth it when possible.



FIGS. 2,618 and 2,619.—**Two curves** *obtained with the* **falling plate camera** and illustrating *the discharge of a condenser through an inductive circuit.* **When taking curve** A the resistance in the circuit was very small compared to the inductance, while **before taking curve** B an additional non-inductive resistance was inserted in the circuit so that the oscillations were damped out much more rapidly although the periodic time remained approximately constant.

Ques. How is the time scale produced?

Ans. Either the surface on which the beam of light falls may be caused to move in a vertical plane with a certain velocity, so that the intersection of the beam and the plane surface traces out a curve connecting current with time (a curve which becomes a permanent record if a sensitized surface be used); or, the surface may remain stationary and in the path of the horizontally vibrating beam may be introduced a mirror which rotates or vibrates about a horizontal axis, thus superposing a vertical motion proportional to time on the horizontal vibration which is proportional to current, and causing the beam of light to trace out a curve connecting current and time on the stationary surface.

Ques. What kind of recording apparatus is used with the Duddell oscillograph?

Ans. A falling plate camera, or a cinematograph film camera.

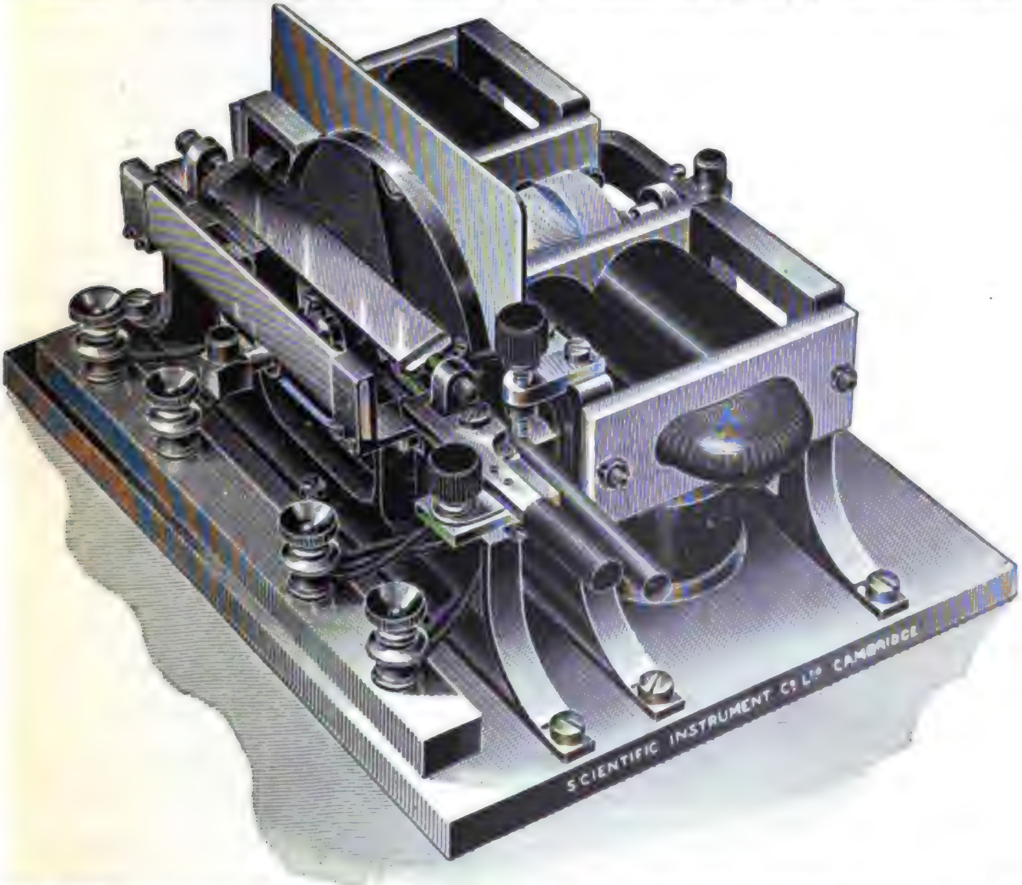
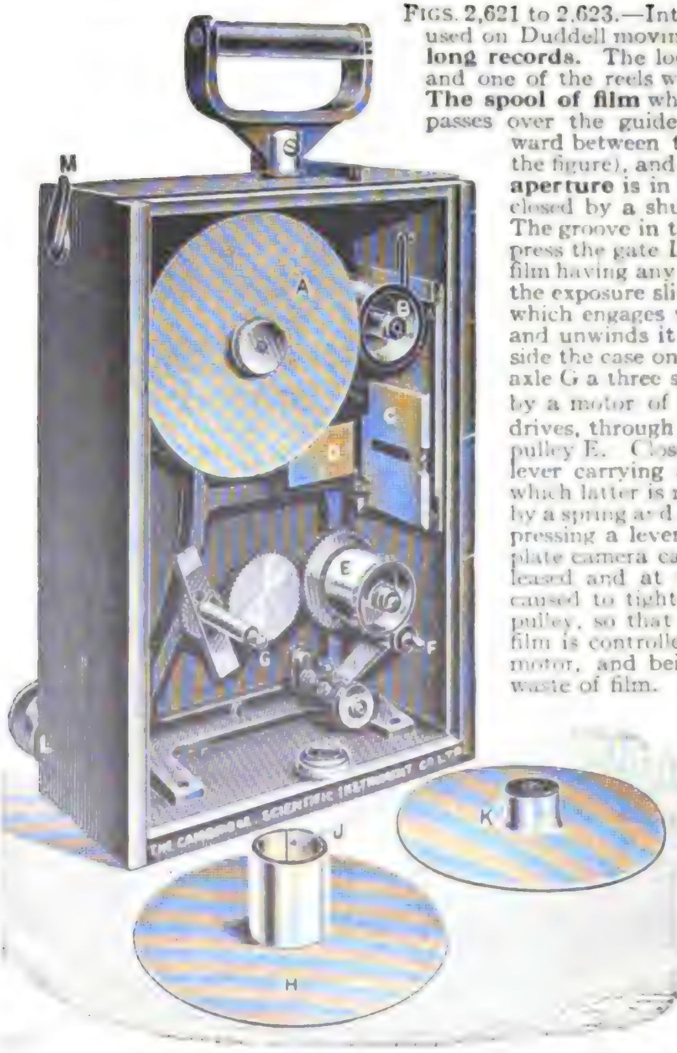


FIG. 2,620.—Synchronous motor with vibrating mirror as used with Duddell moving coil oscillograph. **Since the motor must run synchronously** with the wave form it is required to investigate, *it should be supplied with current from the same source.* The motor can be used over a wide range of frequencies (from 20 to 120). When working at frequencies below 40, it is advisable to increase the moment of inertia of the armature, and for this purpose a suitable brass disc is used. **The armature carries a sector,** *which cuts off the light from the arc lamp during a fraction of each revolution, and a cam which rocks the vibrating mirror.* **It makes one revolution during two complete periods,** and the cam and sector are so arranged that during 1½ periods, the mirror is turning with uniform angular velocity, while during the remaining half period, the mirror is brought back quickly to its angular position, the light being cut off by the sector during this half p

Ques. Explain the operation of the falling plate camera.

Ans. In this arrangement a photographic plate is allowed to fall freely by the force of gravity down a dark slide. At a certain point in its fall it passes a horizontal slit through which the beams of light from the oscillograph pass, tracing out the curves on the plate as it falls.

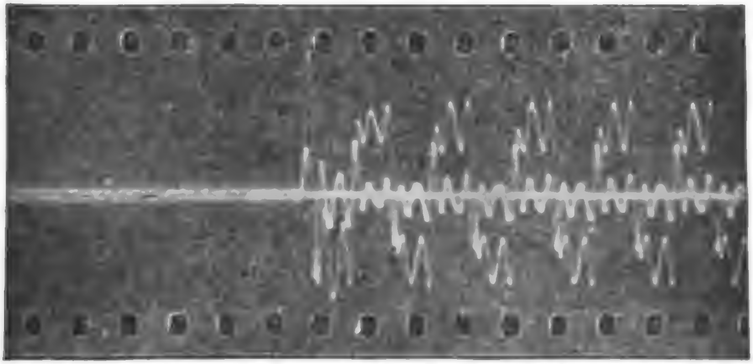
The mean speed of the plate at the moment of exposure is about 13 feet per second. This speed is very suitable for use with frequencies of



FIGS. 2,621 to 2,623.—Interior of cinematograph camera as used on Duddell moving coil oscillograph **for obtaining long records.** The loose side of case is shown removed and one of the reels which carry the film lying in front. **The spool of film** which is placed on the loose reel A, passes over the guide pulley B, then vertically downward between the brass gate D (shown open in the figure), and the brass plate C. **The exposure aperture** is in the plate C and can be opened or closed by a shutter controlled by the lever M. The groove in the plate C, and the springs which press the gate D flat on the plate C, prevent the film having any but a vertical motion as it passes the exposure slit. E is the sprocket driving pulley which engages with the perforations on the film and unwinds it from the reel A to reel H. Outside the case on the far side of it is secured to the axle G a three speed cone pulley. This is driven by a motor of about $\frac{1}{7}$ horse power, which also drives, through the gears shown, the sprocket pulley E. Close to the grooved cone pulley is a lever carrying a jockey pulley L, and a brake, which latter is normally held onto the cone pulley by a spring and so causes the loose belt to slip. By pressing a lever which is attached to the falling plate camera case, the brake can be suddenly released and at the same time the jockey pulley caused to tighten the belt onto the grooved cone pulley, so that the starting and stopping of the film is controlled independently of the driving motor, and being quickly accomplished avoids waste of film. **Both reels** are alike and each is made in two pieces. **The upper reel** is loose on its axle and its motion is retarded slightly by a friction brake. **The lower reel** is also loose on its axle, but it is driven by means of a friction clutch, the clutch always rotating faster than the reel so that the used film delivered by the sprocket pulley E is wound up as fast as delivered. K is the front face of one reel, the boss on it pushes into the tube on the other half H, which serves not only to unite the two halves, but also to secure the end of the film which is doubled through J.

from 40 to 60 periods per second. A cloth bag is used to introduce the plate to the slide.

A catch holds the plate until it is desired to let it fall. Inside the case, is a small motor, 100 or 200 volts direct current, driving four mirrors which are fixed about a common axis with their planes parallel to it.



FIGS. 2,624.—Portion of oscillograph record taken with cinematograph film camera, **showing the rush of current** and **sudden rise of voltage** *at the moment of switching on a high pressure feeder.*

By looking through a small slot in the end of the camera into these rotating mirrors, the observer sees the wave form which the oscillograph is tracing out and is thus able to make sure that he is obtaining the particular wave form or other curve desired before exposing the plate.

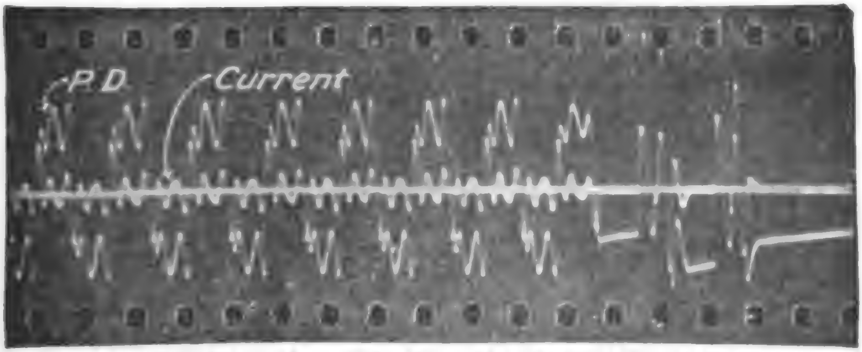


FIG. 2,625.—Portion of oscillograph record taken with a cinematograph film camera **showing the effect of switching off a high pressure feeder** and illustrating the violent fluctuations produced by sparking at the switch contacts.

The plate falls into a second red cloth bag which is placed on the bottom of the slide. The plates used are "stereoscopic size," 6¾" × 3¼" (17.1 × 8.3 cm.).

Ques. For what use is the cinematograph camera adapted?

Ans. For long records.

For instance, in investigations, such as observation on the paralleling of alternators, the running up to speed of motors, and the surges which may occur in switching on and off cable, etc. The cinematograph camera fits on to the falling plate case and by means of which a roll of cinematograph film can be driven at a uniform speed past the exposure aperture, enabling records up to 50 metres in length to be obtained. An interior view of the cinematograph camera is shown in fig. 2,621.

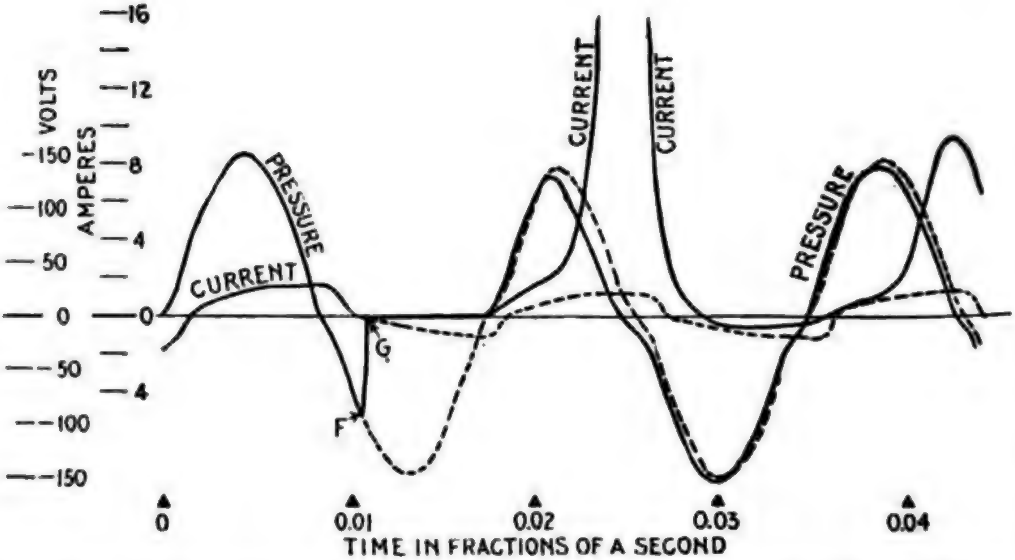


FIG. 2,626.—Curves reproduced from an article by J. T. Morris in the *Electrician*. "On recording transitory phenomena by the oscillograph."

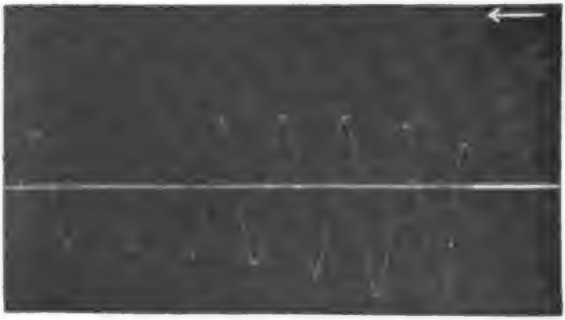
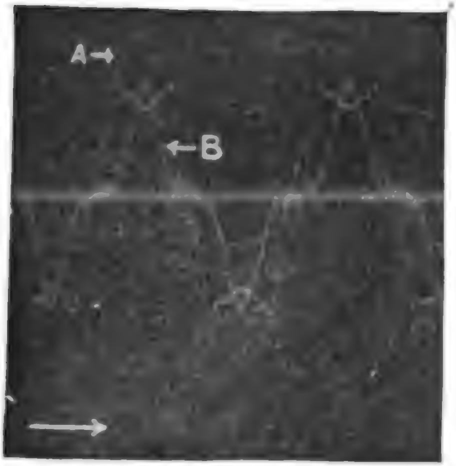


FIG. 2,627.—First rush of current from an alternator when short circuited, showing unsymmetrical initial wave of current, becoming symmetrical after a few cycles. 25 cycles.

FIG. 2,628.—Pressure wave obtained from narrow exploring coil on alternator armature indicating distribution of field flux. The terminal voltage of the alternator is very nearly a sign wave. 60 cycles; about 17 volts.

SOME OSCILLOGRAPH RECORDS



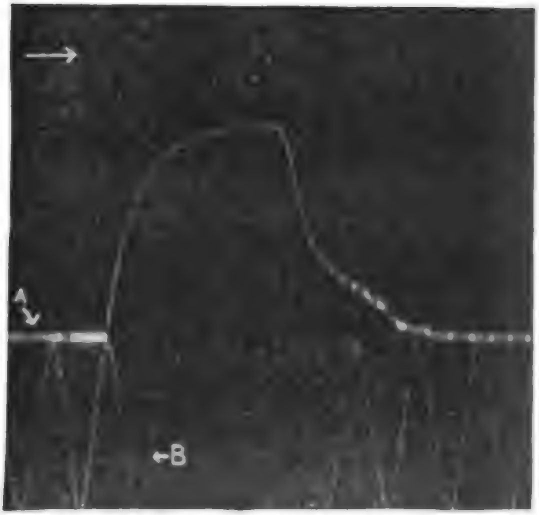


Fig. 2,629.—The waves of voltage and current of an alternating arc. A, voltage wave; B, current wave showing low power factor of the arc without apparent phase displacement. 60 cycles.

Fig. 2,630.—Rupturing 650 volt circuit. A, current wave; B, 25 cycle wave to mark time scale.

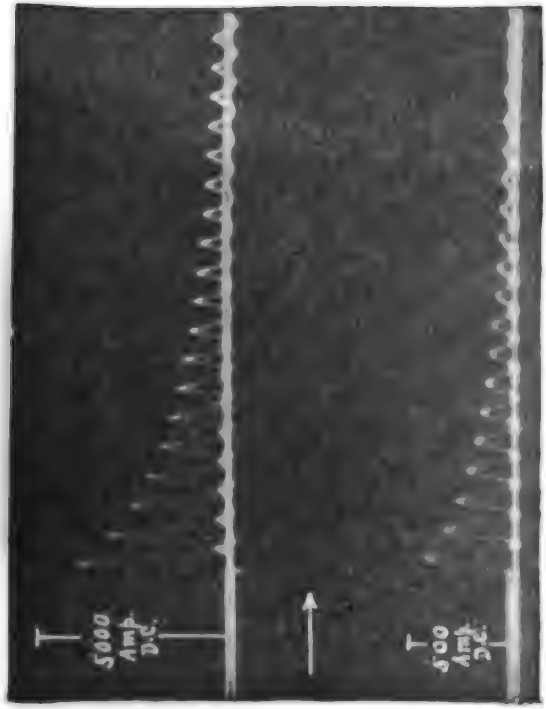


Fig. 2,631.—First rush of current from alternator when short circuited, showing unsymmetrical current wave, also wave of field current caused by short circuit current in armature. Upper curve, armature current; lower curve, field current.

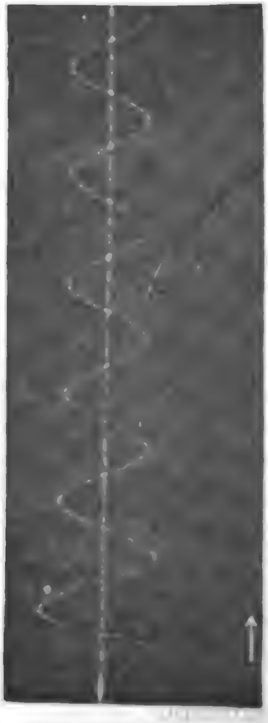


Fig. 2,632.—Mazda (tungsten) lamp, showing rapid decrease to normal current as filament heats up. 25 cycles.

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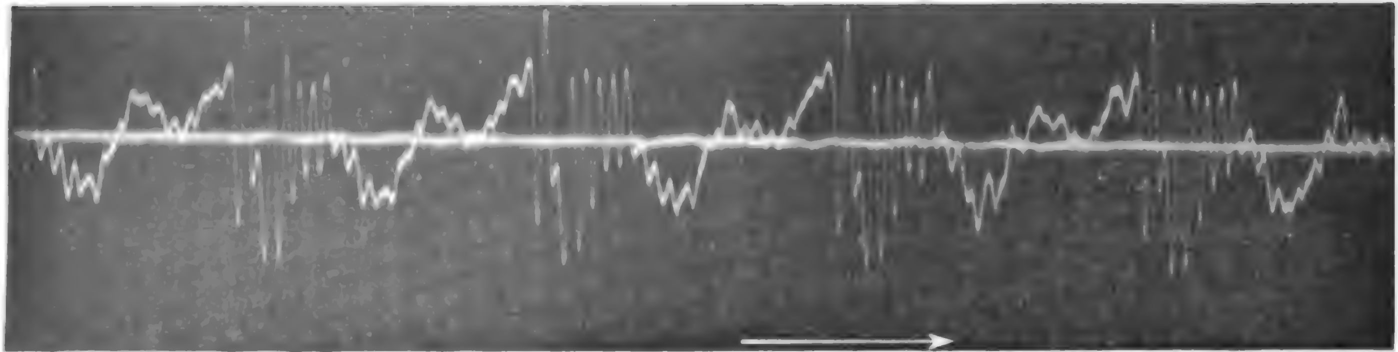


FIG. 2,633.—Current wave in telephone line corresponding to sustained vowel sound "*i*," as in machine; voice pitched at A 110.

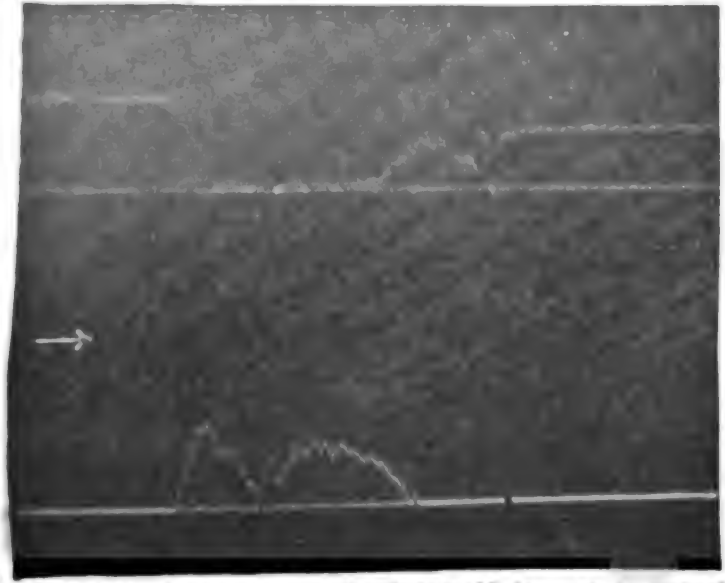


FIG. 2,634.—Carbon lamp, showing rapid increase to normal current as filament heats up. 25 cycles.

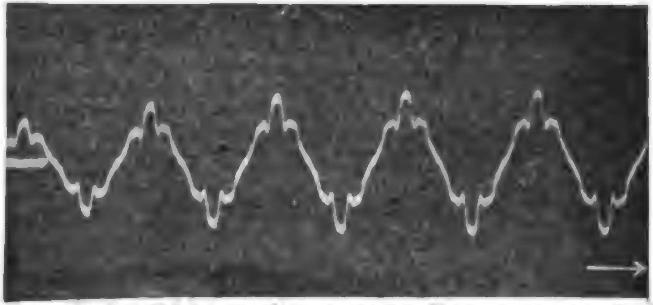


FIG. 2,635.—Short circuit current on direct current end of rotary converter, 21,500 amperes maximum. Upper curve, direct current voltage; lower curve, direct current amperage. Duration of short circuit about .1 second.

CHAPTER LXIV

SWITCHBOARDS

General Principles of Switchboard Connections.—The interconnection of generators, transformers, lines, bus bars, and switches with their relays, in modern switchboard practice is shown by the diagrams, figs. 2,636 to 2,645. The figures being lettered A to J for simplicity, the generators are indicated by black discs, and the switches by open circles, while each heavy line represents a set of bus bars consisting of two or more bus bars according to the system of distribution. It will be understood, also, in this connection, that the number of pole of the switches and the type of switch will depend upon the particular system of distribution employed.

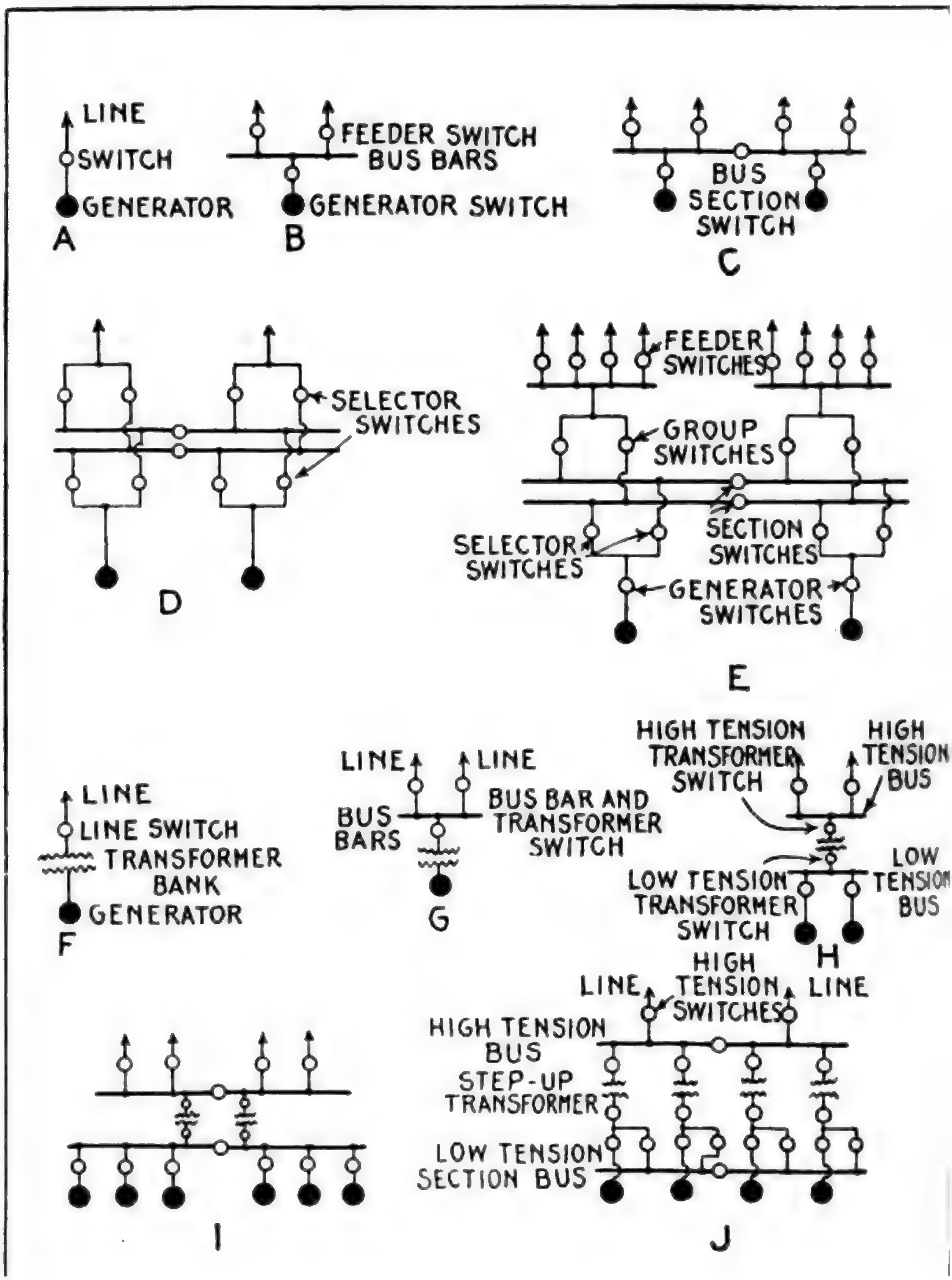
Diagram A, shows the simplest system, or one in which a single generator feeds directly into the line. There are no transformers or bus bars and only one switch is sufficient.

In B, a single generator supplies two or more feeders through a single set of bus bars, requiring a switch for each feeder, and a single generator switch.

In C, two generators are employed and required and the addition of a bus section switch.

D, represents a number of generators supplying two independent circuits. The additional set of bus bars employed for this purpose necessitates an additional bus section switch, and also additional selector switches for both feeders and generators.

E, shows a standard system of connection for a city street railway system having a large number of feeders.


LINE
SWITCH
GENERATOR
A
FEEDER SWITCH
BUS BARS
GENERATOR SWITCH
B
BUS
SECTION
SWITCH
C
SELECTOR
SWITCHES
D
FEEDER
SWITCHES
GROUP
SWITCHES
SECTION
SWITCHES
SELECTOR
SWITCHES
GENERATOR
SWITCHES
E
LINE
LINE SWITCH
TRANSFORMER
BANK
GENERATOR
F
LINE
LINE
BUS
BARS
BUS BAR AND
TRANSFORMER
SWITCH
G
HIGH TENSION
TRANSFORMER
SWITCH
HIGH
TENSION
BUS
LOW
TENSION
BUS
LOW TENSION
TRANSFORMER
SWITCH
H
I
LINE
HIGH
TENSION
SWITCHES
LINE
HIGH TENSION
BUS
STEP-UP
TRANSFORMER
LOW TENSION
SECTION BUS
J

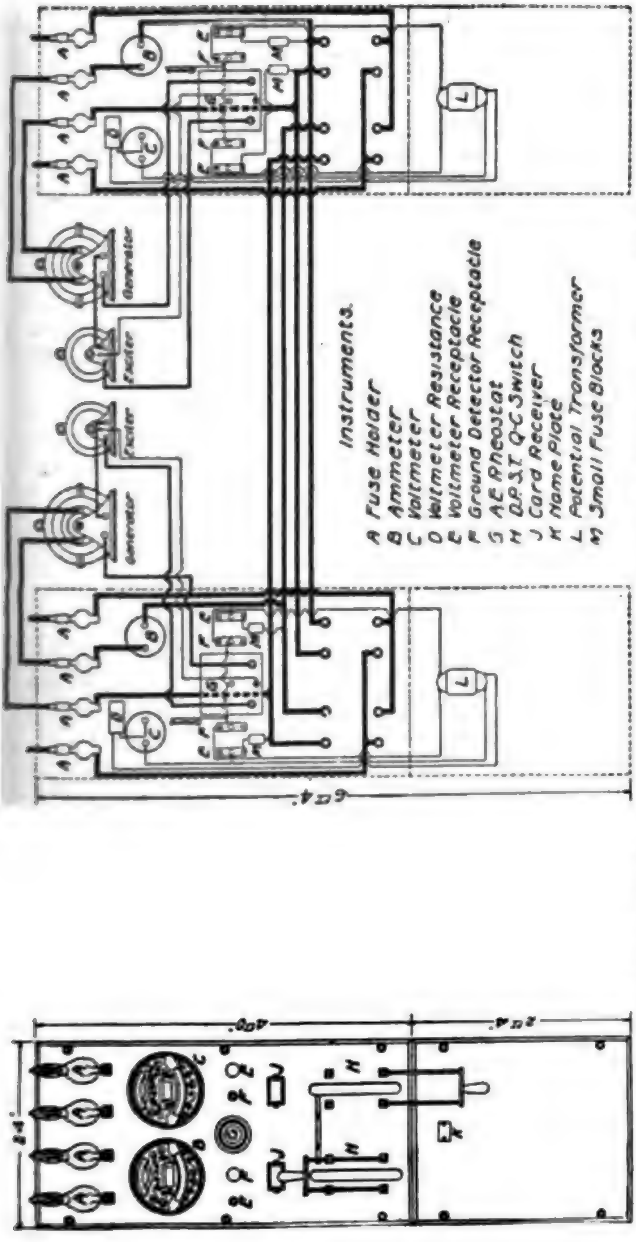

Instruments.
A Fuse Holder
B Ammeter
C Voltmeter
D Voltmeter Resistance
E Voltmeter Receptacle
F Ground Detector Receptacle
G AE Rheostat
H D.P.S.T. Q-C Switch
J Card Receiver
K Name Plate
L Potential Transformer
M Small Fuse Blocks
Generator
Exciter
Exciter
Generator
L
L

FIG. 2,646.—**Fort Wayne switchboard panel for one alternator and one transfer circuit.** Diagram giving dimensions, arrangement of instruments of board, and method of wiring. The different forms of standard alternating current switchboard panels for single phase circuits made by the Fort Wayne Electric Works are designed to fulfill all the usual requirements of switchboards for this class of work. The line includes panels equipped for a single generator; for one generator and two circuits; one generator and one transfer circuit; one generator, an incandescent and an arc lighting circuit; and also feeder panels of different kinds.

This arrangement allows any group of feeders to be supplied from any group of generators.

It also permits the addition of a generator switch for each generator.

F, represents the simplest system with transformers.

It requires a single generator transformer bank, switch and line. The arrangement as shown at F is used where a number of plants supply the same system.

G, represen s a system having more than one line.

In this case a bus bar and transformer switch is used on the high tension side.

H, shows a number of generators connected to a set of low tension bus bars through generator switches, and employing a low tension transformer switch.

I, shows the connections of a system having a large number of feeders supplied by several small generators. In this case, the plant is divided into two parts, each of which may be operated independently.

J, represents the arrangement usually employed in modern plants where the generator capacity is large enough to permit of a generator transformer unit combination with two outgoing lines. By operating in parallel on the high tension side only, any generator can be run with any transformer. The whole plant can be run in parallel, or the two parts can be run separately.

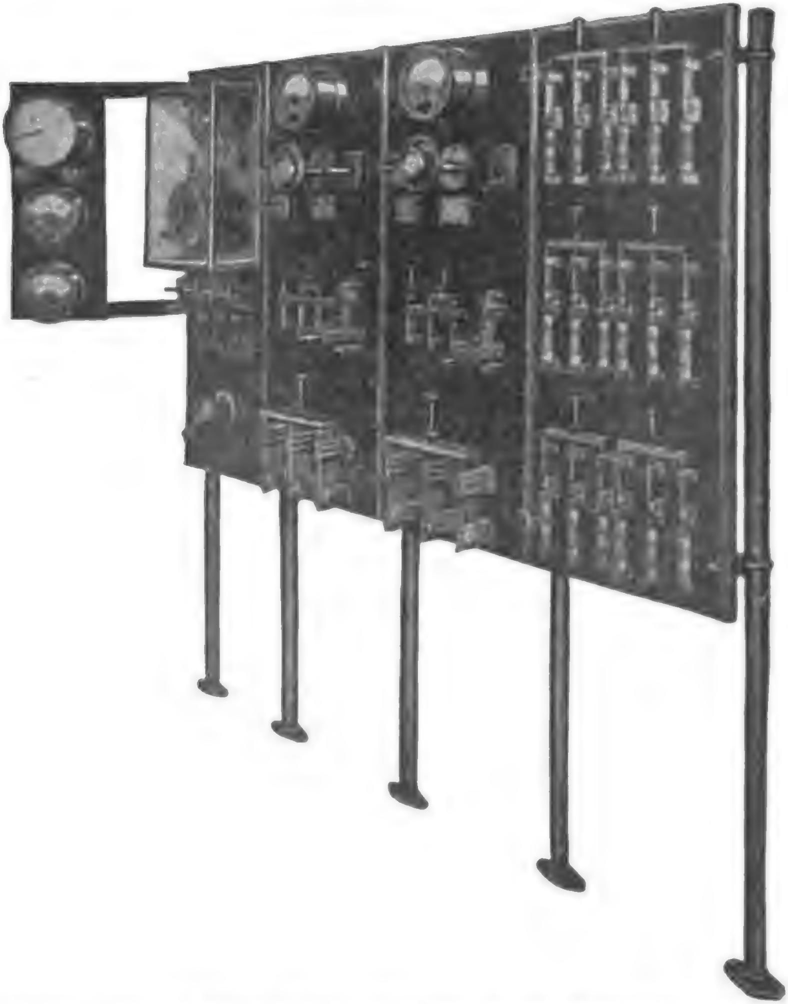


FIG. 2,647.—General Electric **small plant alternating current switchboard**, *designed for use in small central stations and isolated plants.* They are for use with one set of bus bars, to which all generators and feeders are connected by means of single throw lever switches or circuit breakers, suitable provision being made for the parallel operation of the generators.

Switchboard Panels.—The term "panel" means the slab of marble or slate upon which is mounted the switches, and the indicating and controlling devices. There are usually several panels comprising switchboards of moderate or large size, these panels being classified according to the division of the system that they control, as for instance:

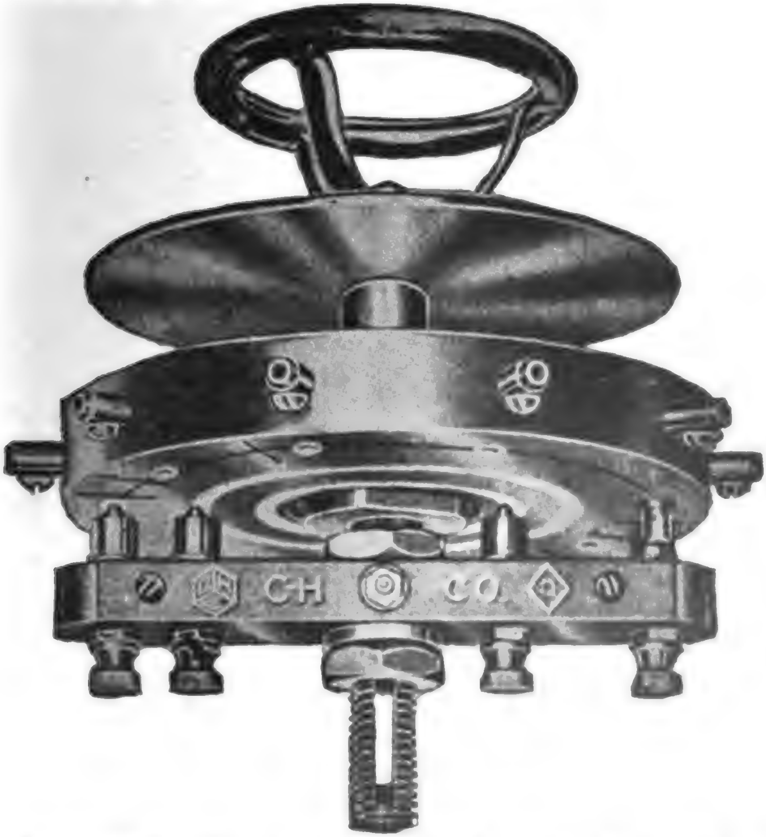
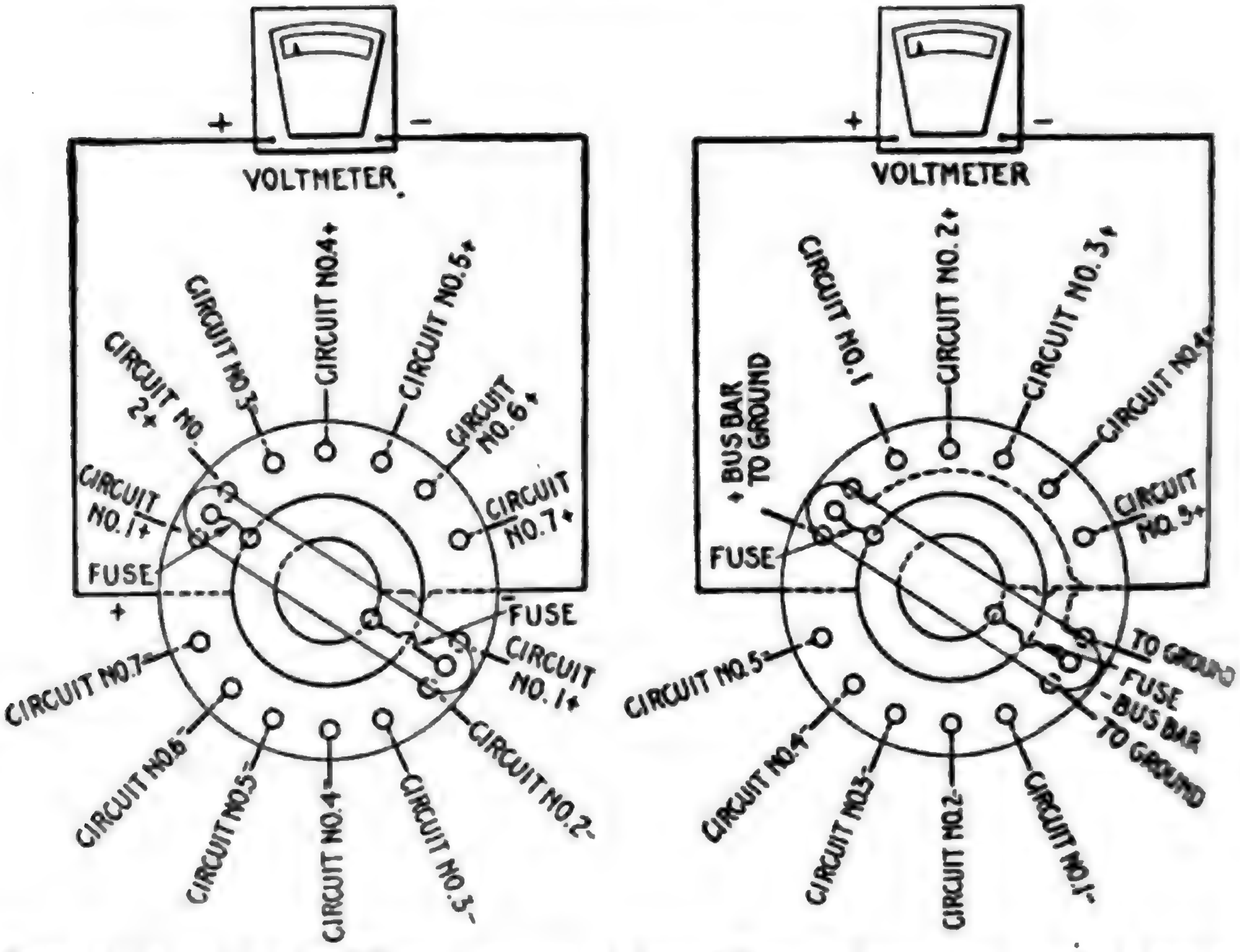


FIG. 2,648.—Crouse-Hinds **voltmeter and ground detector radial switch,** arranged for mounting on the switchboard. The switch proper is placed on the rear of the board with hand wheel, dial, and indicator only on the front side. The current carrying parts are of hard brass, with contact surfaces machined after assembling. The contact parts are of the plunger spring type, and the cross bar has fuse connections. Ground detector circuits are marked G + and G – for two wire system, and G +, G –, GN +, and GN – for three wire system. When the voltmeter switch is to be used as a ground detector, two circuits are required for a two wire system, and four circuits for a three wire system, that is, a six circuit voltmeter and ground detector switch for use on a two wire system has two circuits for ground detector and four circuits for voltmeter readings. A six circuit voltmeter and ground detector switch, for use on a three wire system, has four circuits for ground detector and two circuits for voltmeter readings.

1. Generator panel;
2. Feeder panel;
3. Regulator panel, etc.

In construction, the marble or slate should be free from metallic veins, and for pressures above, say, 600 volts, live connections, terminals, etc., should preferably be insulated from the panels by ebonite, mica or removed from them altogether, as is generally the case with the alternating gear where the switches are of the oil type.

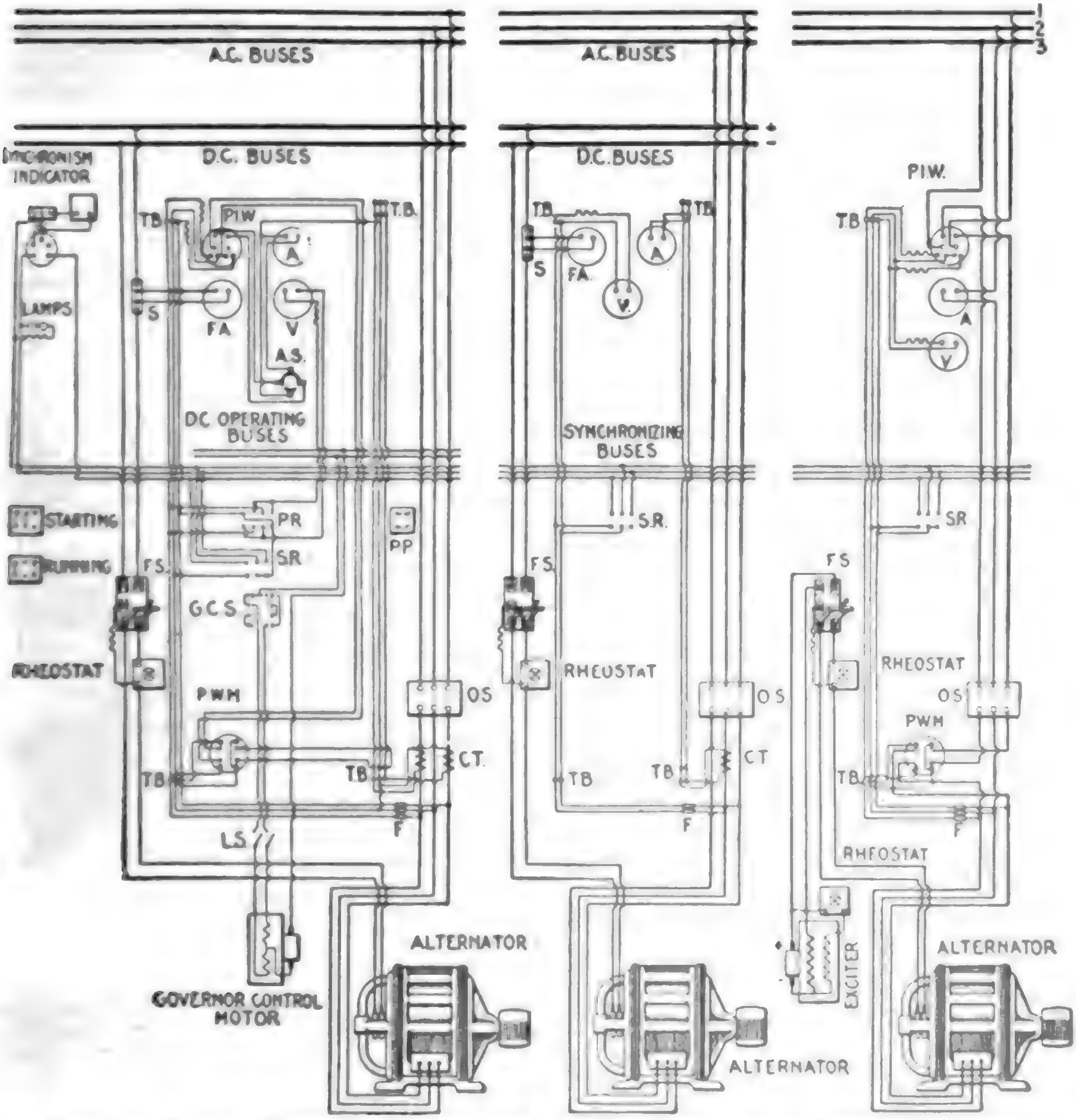

+
−
VOLTMETER
CIRCUIT NO.4+
CIRCUIT NO.5+
CIRCUIT NO.3+
CIRCUIT NO. 2+
CIRCUIT NO.6+
CIRCUIT NO.1+
CIRCUIT NO.7+
FUSE
+
FUSE
CIRCUIT NO.7−
CIRCUIT NO.1+
CIRCUIT NO.6−
CIRCUIT NO.5−
CIRCUIT NO.4−
CIRCUIT NO.3−
CIRCUIT NO.2−
+
−
VOLTMETER
CIRCUIT NO.1
CIRCUIT NO.2+
CIRCUIT NO.3+
CIRCUIT NO.4+
+ BUS BAR TO GROUND
CIRCUIT NO.5+
FUSE
CIRCUIT NO.5−
TO GROUND
FUSE
−BUS BAR
TO GROUND
CIRCUIT NO.4−
CIRCUIT NO.3−
CIRCUIT NO.2−
CIRCUIT NO.1−

Figs. 2,649 and 2,650.—Wiring diagrams of Crouse-Hinds voltmeter and ground detector switches. Fig. 2,649 voltmeter switch; fig. 2,650 voltmeter and ground detector switch. A view of the switch is shown in fig. 2,648; it is designed for use on two or three wire systems up to 300 volts.

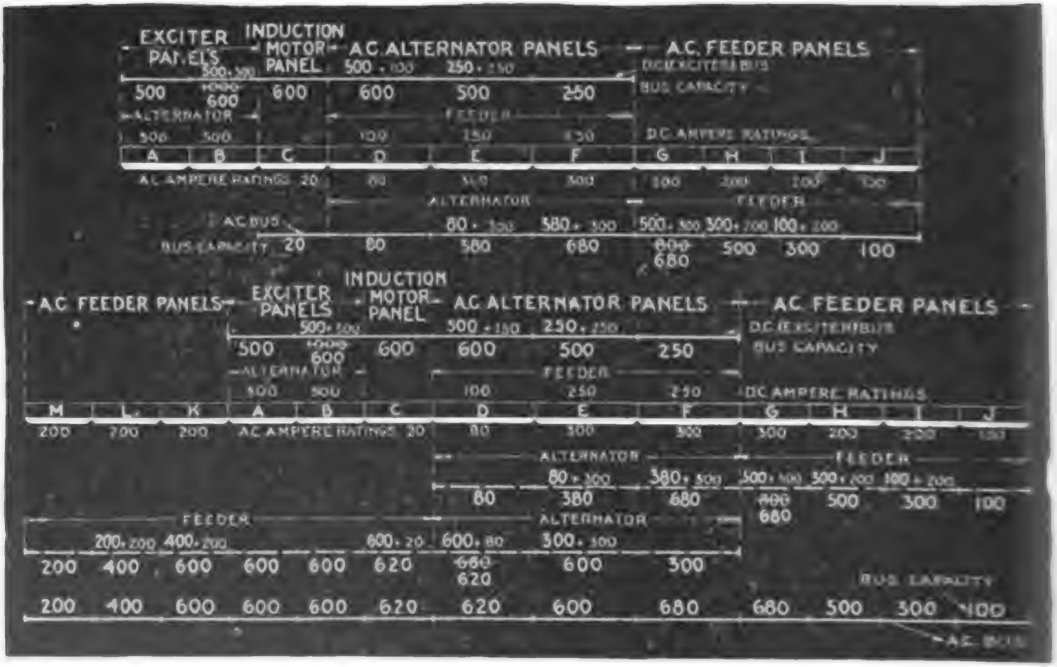
The bus bars and connections should be supported by the framework at the back of the board, or in separate cells, and the instruments should be operated at low pressure through instrument transformers.

The panels are generally held in position by bolting them to an angle iron, or a strip iron framework behind them.

Generator Panel.—This section of a switchboard carries the instruments and apparatus for measuring and electrically controlling the generators. On a well designed switchboard each generator has, as a rule, its own panel.


A.C. BUSES
D.C. BUSES
SYNCHRONISM INDICATOR
LAMPS
TB
PIW
A
FA
V
S
A.S.
T.B.
D.C. OPERATING BUSES
STARTING
RUNNING
PR
PP
SR
F.S.
GCS
RHEOSTAT
PWM
OS
C.T.
F
L.S.
GOVERNOR CONTROL MOTOR
ALTERNATOR
A.C. BUSES
D.C. BUSES
+
-
SYNCHRONIZING BUSES
S.R.
ALTERNATOR
1
2
3
P.I.W.
EXCITER
ALTERNATOR

FIGS. 2,651 to 2,653.—Diagrams of connections for generator panels. **Key to symbols: A.**, ammeter; **A.S.**, ammeter switch; **C.T.**, current transformer; **F.**, fuse; **F.A.**, direct current field ammeter; **F.S.**, field switch; **G.C.S.**, governor control switch; **L.S.**, limit switch (included with governor motor); **O.S.**, oil switch; **P.I.W.**, polyphase indicating wattmeter; **P.W.M.**, polyphase watthour meter; **P.R.**, pressure receptacle; **P.P.**, pressure plug; **Rheo.**, rheostat; **S.**, shunt; **S.R.**, synchronizing receptacle; **S.P.**, synchronizing plugs; **T.B.**, terminal board for instrument leads; **V**, alternating current voltmet


EXCITER PANELS
INDUCTION MOTOR PANEL
A.C. ALTERNATOR PANELS
A.C. FEEDER PANELS
D.C. (EXCITER) BUS
BUS CAPACITY
ALTERNATOR
FEEDER
D.C. AMPERE RATINGS
A
B
C
D
E
F
G
H
I
J
K
L
M
A.C. AMPERE RATINGS
A.C. BUS
500 + 500
500 + 100
250 + 250
500
1000
600
250
100
80 + 300
380 + 300
500 + 300
300 + 200
100 + 200
20
80
380
680
800
680
300
200 + 200
400 + 200
600 + 20
600 + 80
300 + 300
200
400
620
660
620
A.C. BUS

Figs. 2,654 and 2,655.—Diagrams illustrating **a simple method of determining bus capacity** as suggested by the General Electric Co. Fig. 2,654 relates to any panel; the method is as follows: **1.** Make a rough plan of the *entire board*, regardless of the number of panels to be ordered. *The order of panels* shown is recommended, it being most economical of copper and best adapted to future extensions. **2.** To avoid confusion keep on one side of board everything pertaining to exciter buses, and on other side everything pertaining to A. C. buses. **3.** With single lines represent the exciter and A. C. buses across such panels as they actually extend and by means of arrows indicate that portion of each bus which is connected to feeders and that portion which is connected to generators. *Remember that "Generator" and "Feeder" arrows must always point toward each other*, otherwise the rules given below do not hold. Note also that the field circuits of alternator panels are treated as D. C. feeders for the exciter bus. **4.** On each panel mark its ampere rating, that is, the maximum current it supplies to or takes from the bus. For A. C. alternator panels the D. C. rating is the excitation of the machines. **5.** Apply the following rules *consecutively*, and note their application in fig. 2,654. (For the sake of clearness ampere ratings are shown in light face type and bus capacities in large type.) **A.** *Always begin with the tail of the arrow and treat "generator" and "feeder" sections of the bus separately.* **B.** *Bus capacity for first panel = ampere rating of panel.* **C.** *Bus capacity for each succeeding panel = ampere rating of panel* plus *bus capacity for preceding panel.* (See sums marked above the buses in fig. 2,654.) **D.** *For a panel not connected to a bus extending across it, use the smaller value of the bus capacities already obtained for the two adjoining panels.* (See exciter bus for panel C.) **E.** *The bus capacity for any feeder panel need not exceed the maximum for the generator panels* (see A. C. bus for panel G) *and vice versa* (see exciter bus for panel B). Hence the corrections made in values obtained by applying rules **B** and **C.** The arrangement of panels shown in fig. 2,654 is the one which is mostly used. The above method may, however, be applied to other arrangements, one of which is shown in fig. 2,655. Here the generators must feed both ways to the feeders at either end of the board so that in determining A. C. bus capacities it is necessary to first consider the generators with the feeders at one end, and then with the feeders at the other end as shown by the dotted A. C. buses. The required bus capacities are then obtained by taking the maximum values for the two cases.

In the case of a dynamo, a good representative panel would have mounted upon it a reverse current circuit breaker, an ammeter, a double pole main switch (or perhaps a single pole switch, since the circuit breaker could also be used as a switch) a double pole socket into which a plug could be inserted to make connection with a voltmeter mounted on a swinging bracket at the end of the board; a rheostat handle, the spindle of which

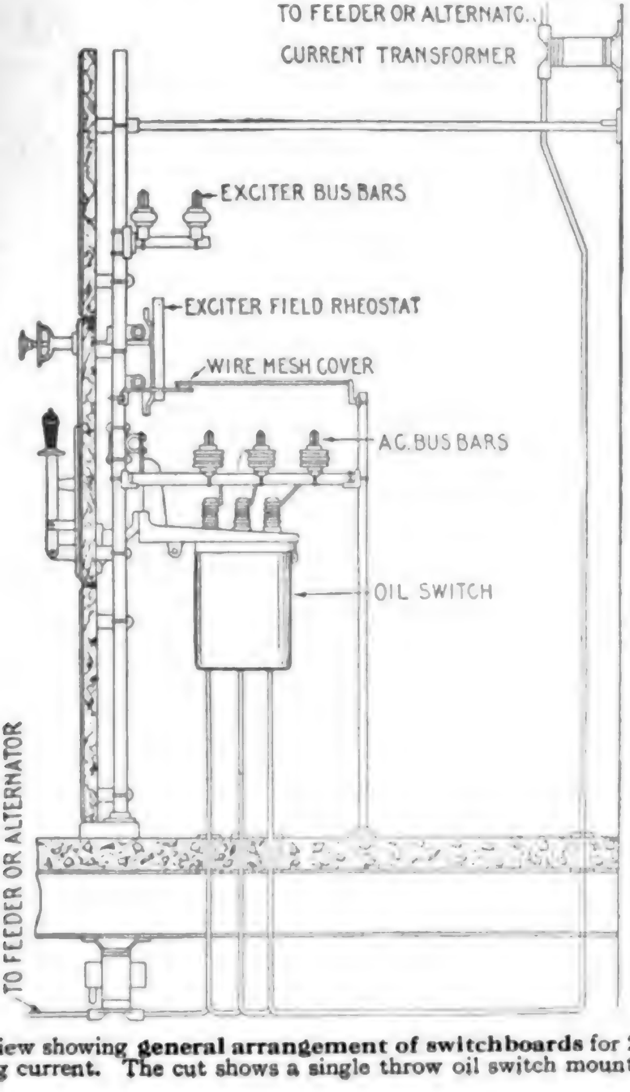
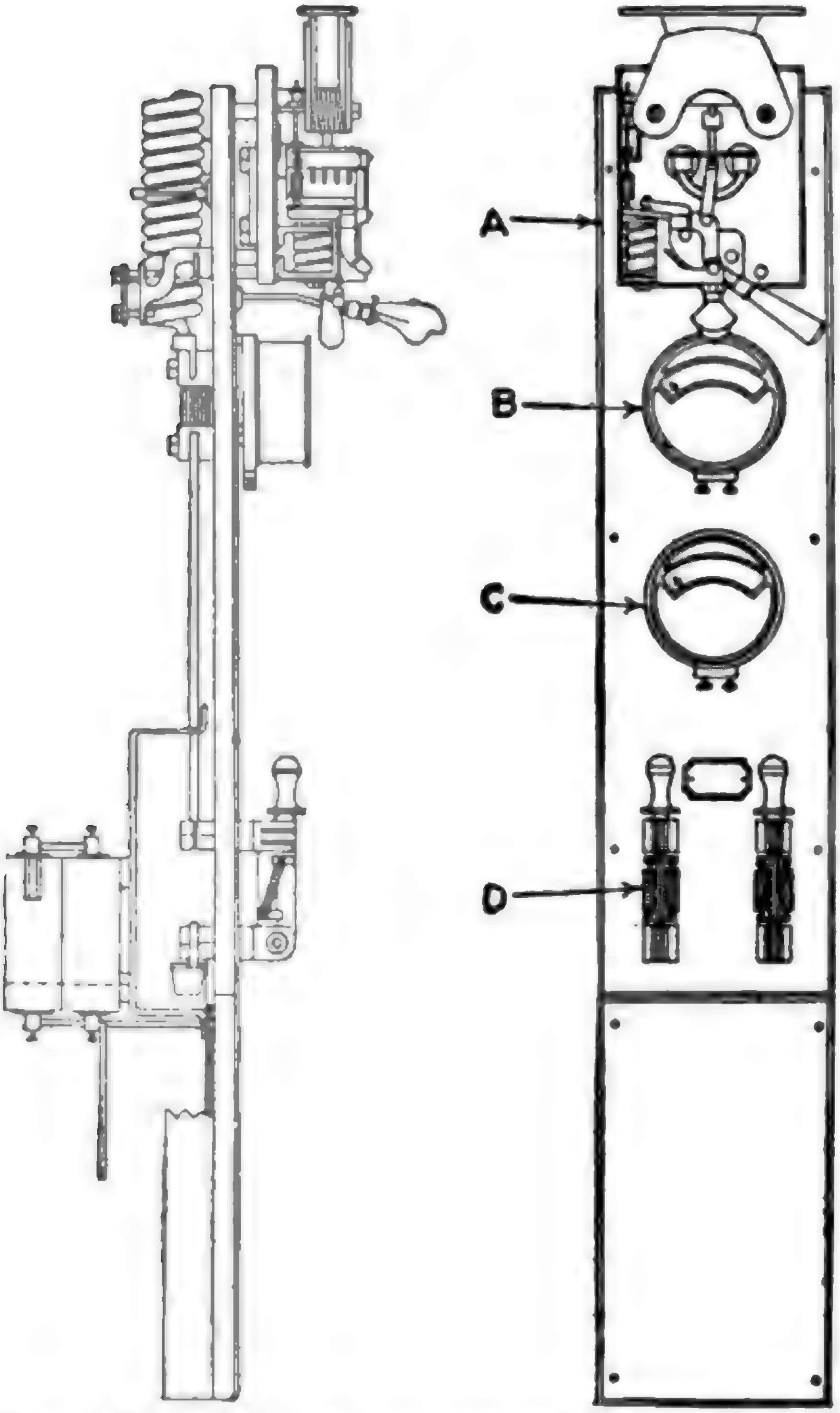
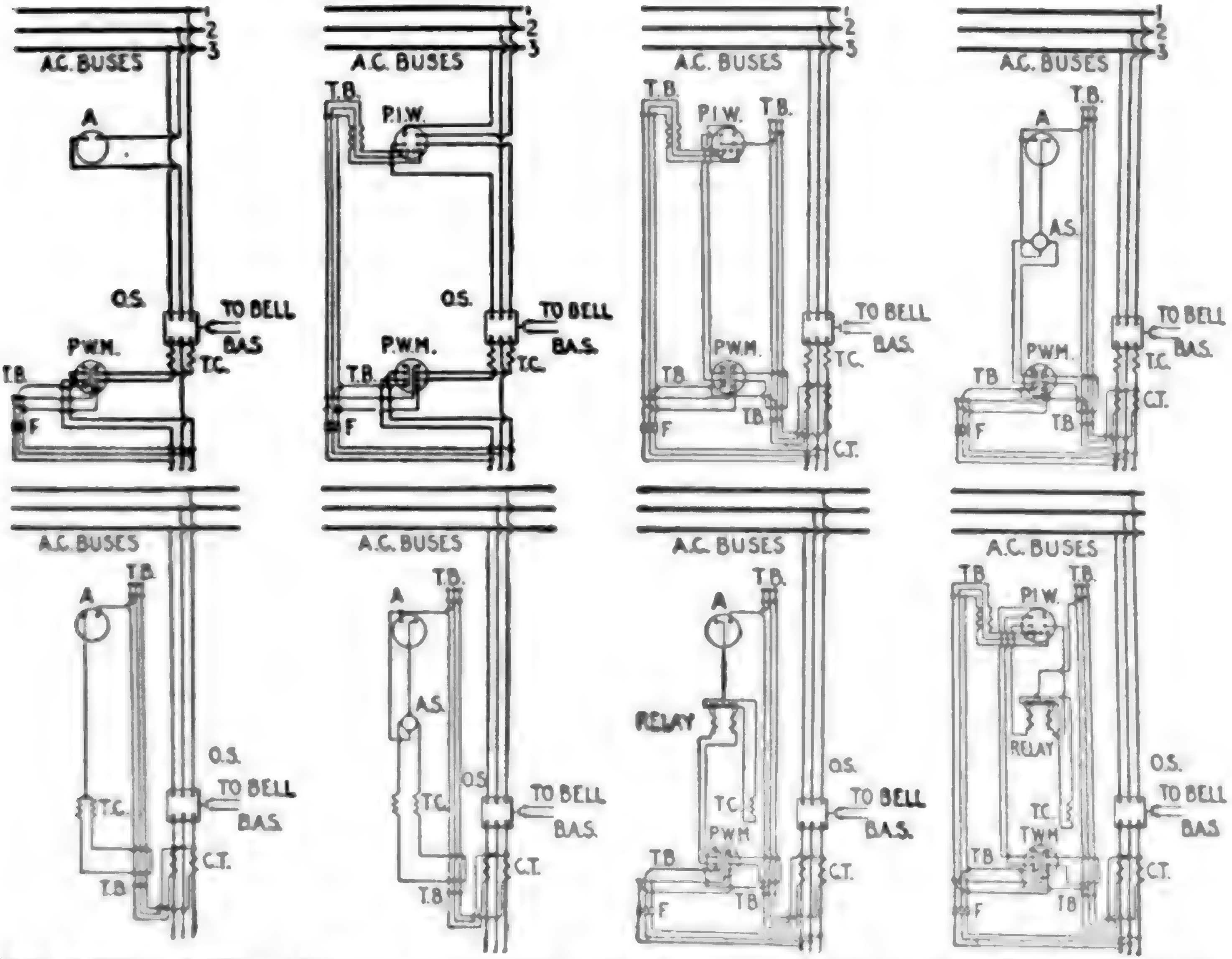

TO FEEDER OR ALTERNATO..
CURRENT TRANSFORMER
EXCITER BUS BARS
EXCITER FIELD RHEOSTAT
WIRE MESH COVER
A.C. BUS BARS
OIL SWITCH
TO FEEDER OR ALTERNATOR

FIG. 2,656.—**End view showing general arrangement of switchboards** for 240, 480, and 600 volt alternating current. The cut shows a single throw oil switch mounted on the pane' operates the shunt rheostat of the machine, the rheostat being placed either directly behind the spindle, if of small size, or lower down with chain drive from the hand wheel spindle, if of larger size, a field discharge switch and resistance, a lamp near the top of the panel for illumintaing purposes, a fuse for the voltmeter socket, and, if desired, a watthour meter. If the dynamo be compound wound, the equalizing switch will generally be mounted on the frame of the machine, and in some cases the field rheostat will be operated from a pillar mounted in front of the switchboard gallery. If the generator be for traction purposes, the circuit breaker is more often of the maximum current type, and a lightning arrester is often added, without a choke coil, the latter as well as further lightning arresters being mounted on the feeder panels.



FIGS. 2,657 and 2,658.—Two views of a **feeder panel**, showing general arrangement of the devices assembled thereon. A, circuit breaker; B, ammeter; C, voltmeter; D,. switches.

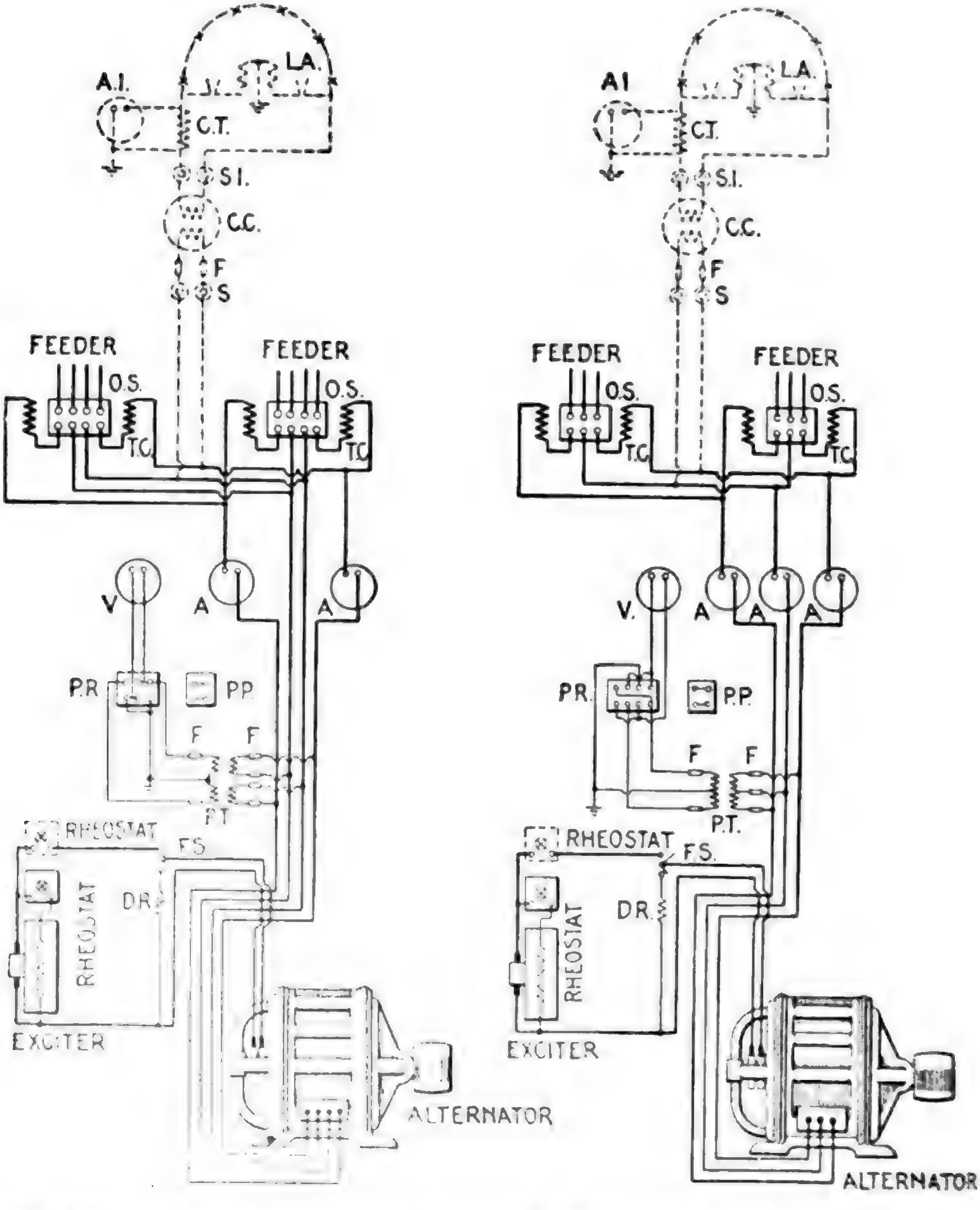
In the case of a high pressure alternating current plant of considerable size, the bus bars oil switches, and the current and pressure transformers are generally mounted either in stoneware cells, or built on a framework in a space guarded by expanded metal walls, and no high pressure apparatus of any sort is brought on to the panels themselves.


1
2
3
A.C. BUSES
A
O.S.
TO BELL
B.A.S.
P.W.M.
T.C.
T.B.
F
1
2
3
A.C. BUSES
T.B.
P.I.W.
O.S.
TO BELL
B.A.S.
P.W.M.
T.C.
T.B.
F
1
2
3
A.C. BUSES
T.B.
P.I.W.
T.B.
TO BELL
B.A.S.
P.W.M.
T.C.
T.B.
T.B.
F
C.T.
1
2
3
A.C. BUSES
T.B.
A
A.S.
TO BELL
B.A.S.
P.W.M.
T.C.
C.T.
T.B.
T.B.
F
A.C. BUSES
T.B.
A
O.S.
TO BELL
B.A.S.
T.C.
C.T.
T.B.
A.C. BUSES
T.B.
A
A.S.
O.S.
T.C.
TO BELL
B.A.S.
C.T.
T.B.
A.C. BUSES
T.B.
A
RELAY
O.S.
TO BELL
B.A.S.
T.C.
PWH
T.B.
T.B.
C.T.
F
A.C. BUSES
T.B.
T.B.
P.I.W.
RELAY
O.S.
TO BELL
B.A.S.
T.C.
TWH
T.B.
C.T.
T.B.
F

Figs. 2,659 to 2,666.—Diagram of connections for three phase feeder panels. **Key to symbols:** A, ammeter; A.S., three way ammeter switch; B.A.S., bell alarm switch; C.T., current transformer; F, fuse; O.S., oil switch; P.I.W., polyphase indicating wattmeter; P.W.M., polyphase watthour meter; T.B., terminal board; T.C., trip coils for oil switch.

Feeder Panel.—The indicating and control apparatus for a feeder circuit is assembled on a panel called the feeder panel.

The most common equipment in the case of a direct current feeder panel comprises an ammeter, a double pole switch, and double pole fuses or instead of the fuses, a circuit breaker on one or both poles; in the case of a traction feeder a choke coil and a lightning arrester are often added.


A.I.
L.A.
C.T.
S.I.
C.C.
F
S
FEEDER
O.S.
T.C.
FEEDER
O.S.
T.C.
V
A
A
P.R
P.P
F
F
P.T
RHEOSTAT
F.S
DR
RHEOSTAT
EXCITER
ALTERNATOR
A1
L.A.
C.T.
S.I.
C.C.
F
S
FEEDER
O.S.
T.C.
FEEDER
O.S.
T.C.
V.
A
A
A
P.R.
P.P.
F
F
P.T.
RHEOSTAT
F.S.
DR.
RHEOSTAT
EXCITER
ALTERNATOR

FIGS. 2,667 and 2,668.—Diagrams of connections for two phase and three phase installations: A and A1, ammeter; C.C., constant current transformer; C.T., current transformer; D.R., discharge resistance; F, fuse; F.S., field switch; L.A., lightning arrester; O.S., oil switch; P.P., pressure plug; P.R., pressure receptacle; P.T., pressure transformer; S and S1, plug switches; T.C., oil switch trip coil; V, voltmeter.

The equipment of a typical high pressure three phase feeder panel is an ammeter (sometimes three ammeters, one in each phase) operated by a current transformer, and oil break switch with two overload release coils, or three if the neutral of the circuit be earthed, the releases being operated by current transformers.

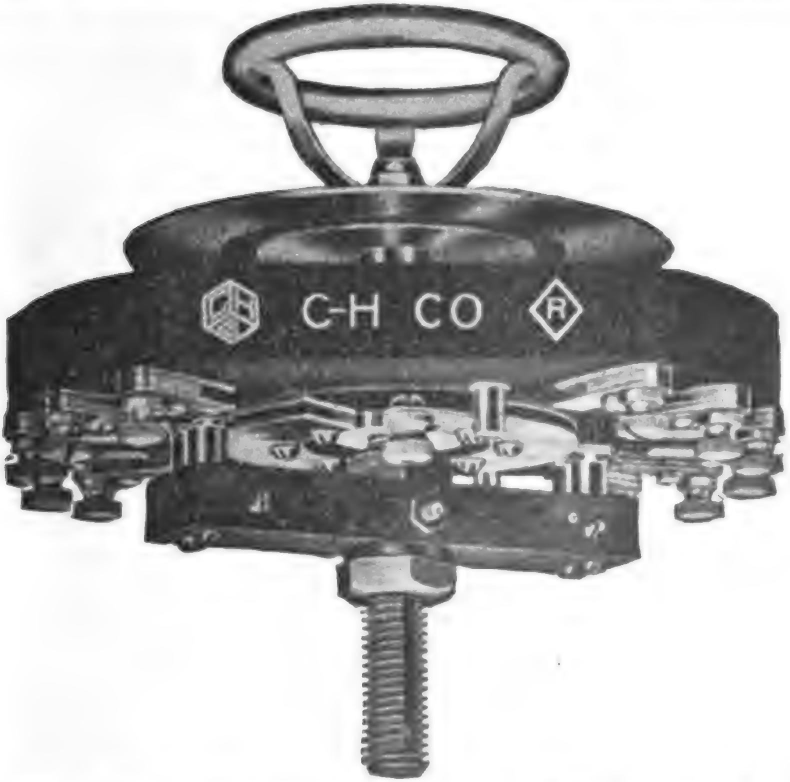


Fig. 2,669.—Crouse-Hinds radial ammeter switch, arranged for mounting directly on the switchboard. It is designed for use with external shunt ammeters of any make or capacity, and in connection with the required number of shunts, makes possible the taking of current readings of a corresponding number of circuits by means of one ammeter. The wiring diagram is shown in fig. 2,670.

The switch when on a large system is often in a cell some listance behind the panel, and is then controlled by a system of evers, or by a small motor which is started and stopped by a hrow over switch on the panel, in which case there is generally lamp or lamps on the panel to show whether the switch is open r closed.

Air brake switches or links are placed between the bus bars and the oil switch to allow of the latter being isolated for inspection purposes, and as a general rule no apparatus carrying high pressure current is allowed on the front of the panel. With both direct and alternating current feeders, a watthour meter is often added to show the total consumption of the circuit.

A typical three phase generator panel is provided with three ammeters, one in each phase, operated from three current transformers, one to each ammeter, a volt meter, a power factor indicator, and an indicating watthour meter, all operated from one or more pressure transformers, and the necessary current transformers, the operating handle of the oil switch, which is connected to the switch itself by means of rods, two maximum releases operated by current transformers, or a reverse relay for automatically tripping the switch, lamps for indicating when the switch it tripped, a socket for taking the plug which makes connection between the secondary of a pressure transformer and the synchronizer on the synchronizing panel, and a lamp for illuminating purposes, while on the base of the panel or on a pillar at the front of the gallery is mounted the gear for the field circuit. This consists of a double pole field switch and a discharge resistance, an ammeter, a handle for the rheostat in the generator field, and (if each alternator have its own direct coupled exciter) possibly also a small rheostat for the exciter field.

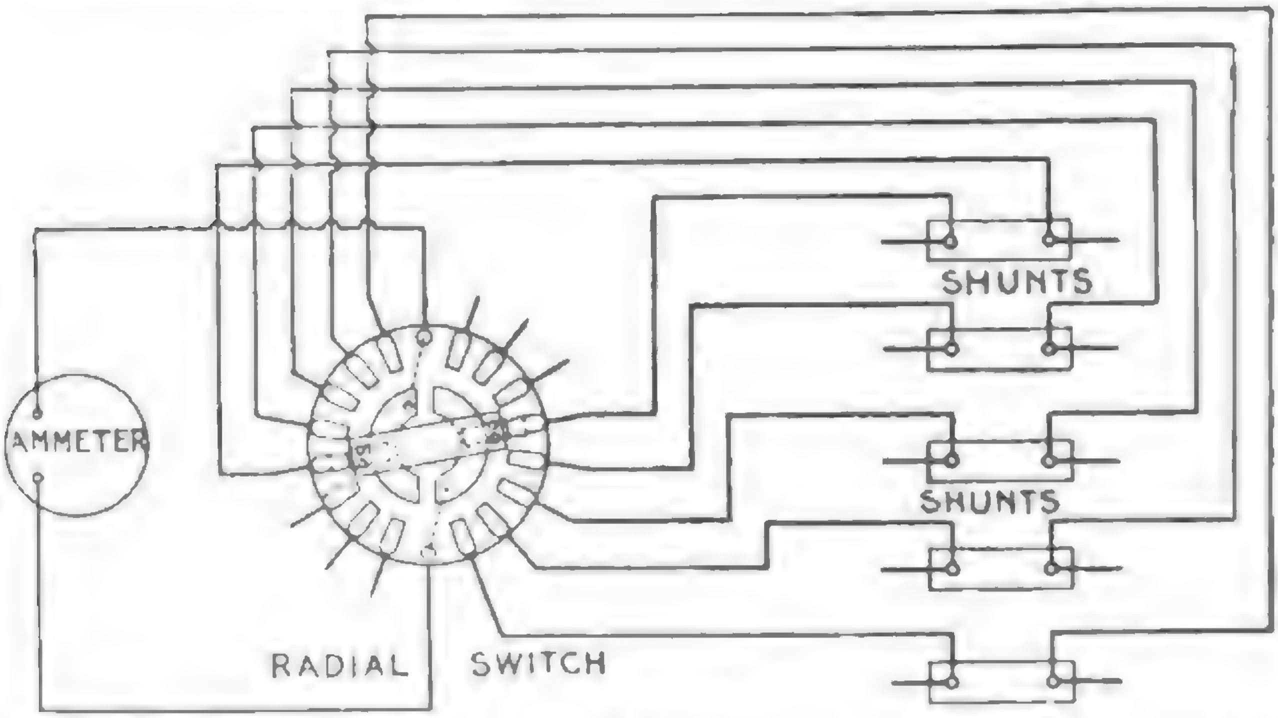


FIG. 2,670.—Wiring diagram for Crouse-Hinds radial ammeter switch as illustrated in fig. 2,669. The switch proper is on the rear of the switchboard, and the hand wheel dial and indicator on the front.

NOTE.—In some cases where the capacity of the plant is not very great, the oil switch is mounted on the back of the panel, and the bus bars, current transformers, &c., on the framework also just at the back of the panel, but under no circumstances, in good modern practice, is high pressure apparatus permitted on the front of the board. Where the capacity of the plant is very large, the oil switches are operated electrically by means of small motors, and in this case the small switch gear for starting and stopping this motor is mounted on the generator panel, also the lamp or lamps to indicate when the switch is open, and when closed.

CHAPTER LXV

ALTERNATING CURRENT WIRING

In the case of alternating current, because of its peculiar behaviour, there are several effects which must be considered in making wiring calculations, which do not enter into the problem with direct current.

Accordingly, in determining the size of wires, allowance must be made for

1. Self-induction;
2. Mutual-induction;
3. Power factor;
4. Skin effect;
5. Corona effect;
6. Frequency;
7. Resistance.

Most of these items have already been explained at such length, that only a brief summary of facts need be added, to point out their connection and importance with alternating current wiring.

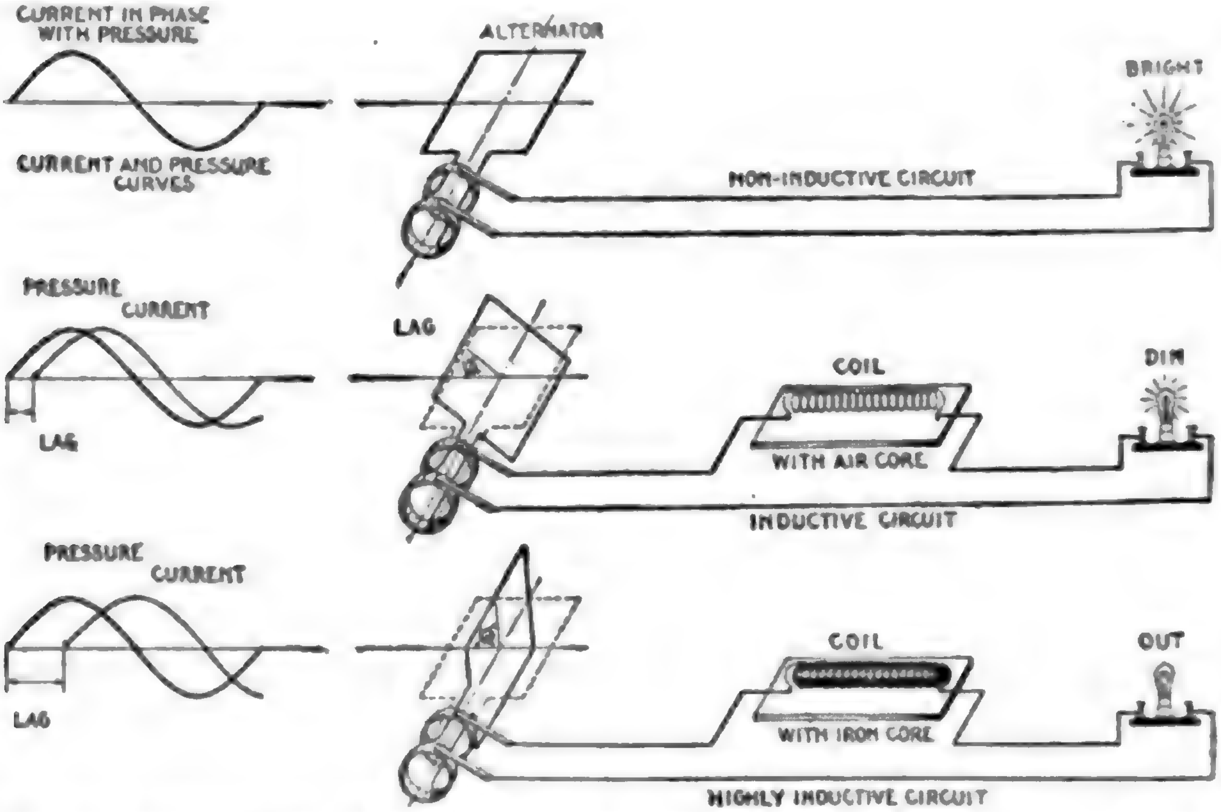
Induction.—The effect of induction, whether self-induction or mutual induction, is to set up a back pressure of *spurious resistance*, which must be considered, as it sometimes materially affects the calculation of circuits even in interior wiring.

Self-induction is the effect produced by the action of the electric current upon itself during variations in strength.

Ques. What conditions besides variations of current strength governs the amount of self-induction in a circuit?

Ans. The shape of the circuit, and the character of the surrounding medium.

If the circuit be straight, there will be little self-induction, but if coiled, the effect will become pronounced. If the surrounding medium be air, the self-induction is small, but if it be iron, the self-induction is considerable.


CURRENT IN PHASE WITH PRESSURE
ALTERNATOR
BRIGHT
CURRENT AND PRESSURE CURVES
NON-INDUCTIVE CIRCUIT
PRESSURE
CURRENT
LAG
LAG
COIL
DIM
WITH AIR CORE
INDUCTIVE CIRCUIT
PRESSURE
CURRENT
COIL
OUT
LAG
WITH IRON CORE
HIGHLY INDUCTIVE CIRCUIT

FIGS. 2,671 to 2,676.—**The effect of self-induction.** In a non-inductive circuit, as in fig. 2,672, the whole of the virtual pressure is available to cause current to flow through the lamp filament, hence it will glow with maximum brilliancy. If an inductive coil be inserted in the circuit as in fig. 2,674, the reverse pressure due to self-induction will oppose the virtual pressure, hence the effective pressure (which is the difference between the virtual and reverse pressures), will be reduced and the current flow through the lamp diminished, thus reducing the brilliancy of the illumination. The effect may be intensified to such degree by interposing an iron core in the coil as in fig. 2,676, as to extinguish the lamp.

Ques. With respect to self-induction, what method should be followed in wiring?

Ans. When iron conduits are used, the wires of each circuit should not be installed in separate conduits, because such arrangement will cause excessive self-induction.

The importance of this may be seen from the experience of one contractor, who installed feeders and mains in separate iron pipes. When the current was turned on, it was found that the self-induction was so great as to reduce the pressure to such an extent that the lamps, instead of giving full candle power, were barely red. This necessitated the removal of the feeders and main and re-installing them, so that those of the same circuit were in the same pipe.

Ques. What is mutual induction?

Ans. Mutual induction is the effect of one alternating current circuit upon another.

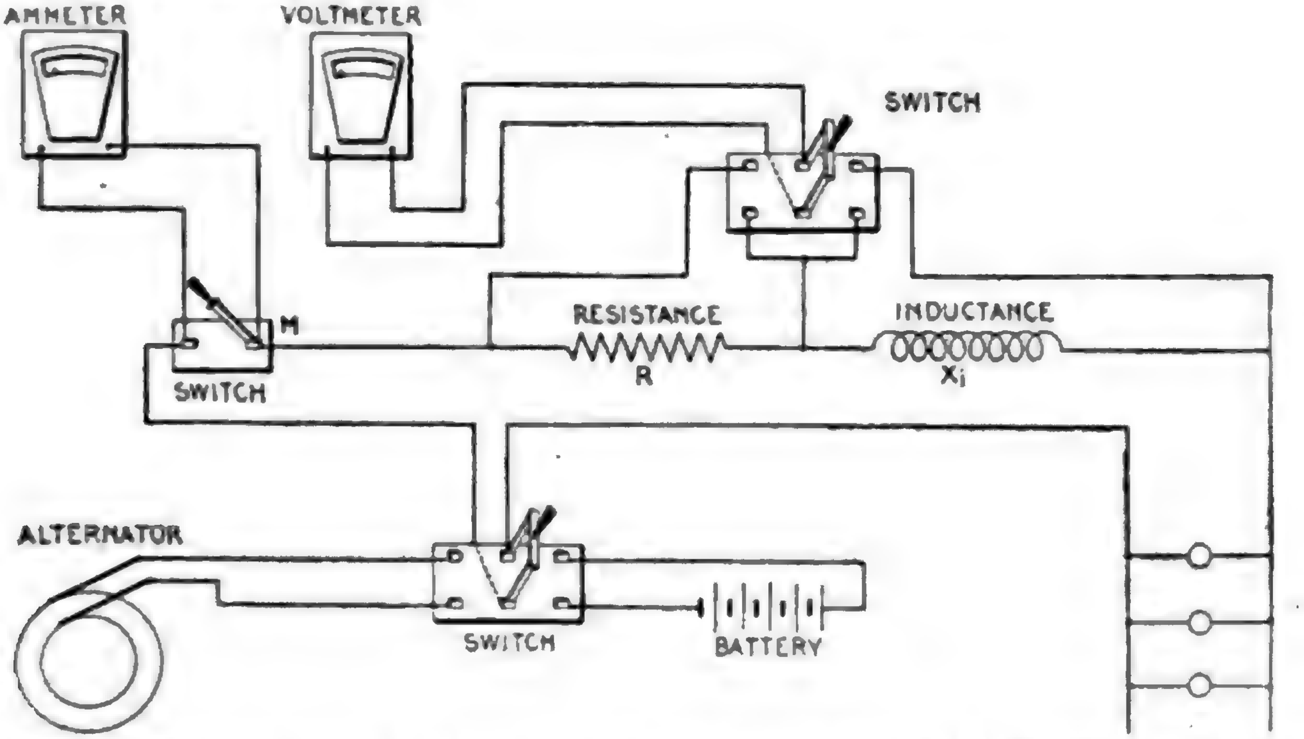


FIG. 2,677.—Measurement of self induction when the frequency is known. The apparatus required consists of a high resistance or electrostatic a.c. voltmeter, d.c. ammeter, and a non-inductive resistance. Connect the inductive resistance to be measured as shown, and close switch M, short circuiting the ammeter. Connect alternator in circuit and measure drop across R and across X_i. Disconnect alternator and connect battery in circuit, then open switch M and vary the continuous current until the drop across R is the same as with the alternating current, both measurements being made with the same voltmeter; read ammeter, and measure drop across X_i. Call the drop across X_i with alternating current E, and with direct current E_i, and the reading of the ammeter J. Then $L = \sqrt{E^2} + E_i^2 \div 2\pi f I$. If the resistance X_i be known, and the ammeter be suitable for use with alternating current, the switch and R may be dispensed with. Then $L = \sqrt{E^2 - X_i^2 I_i^2} \div 2\pi f I$, where I_i is the value of the alternating current. The resistance of the voltmeter should be high enough to render its current negligible as compared with that through X_i.

Ques. How is it caused?

Ans. It is due to the magnetic field surrounding a conductor cutting adjacent conductors and inducing back pressures therein.

This effect as a rule in ordinary installations is negligible.

Transpositions.—The effect of mutual induction between two circuits is proportional to the inter-linkage of the magnetic fluxes of the two lines. This in turn depends upon the proximity of the lines and upon the general relative arrangement of the conductors.

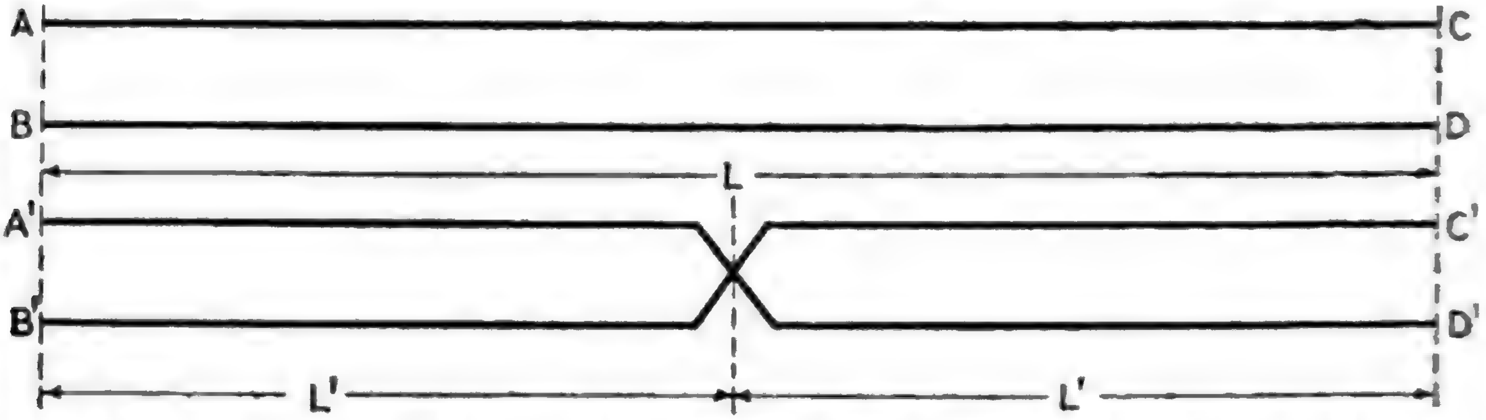


FIG. 2,678.—Transposition diagram for two parallel lines consisting of two wires each.

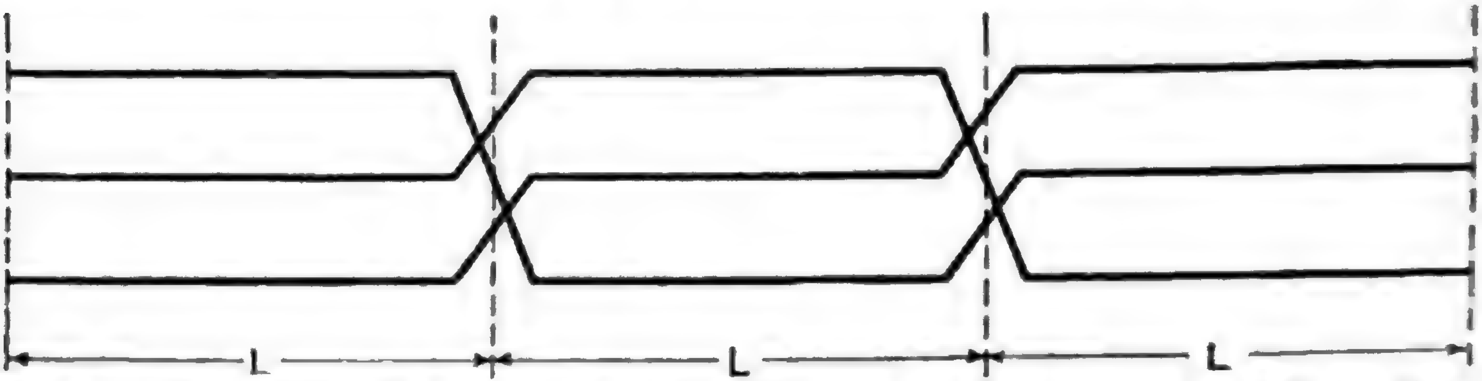


FIG. 2,679.—Transposition diagram for three phase, three wire line, transposing at the vertices of an equilateral triangle. The line is originally balanced and becomes unbalanced on transposing, a procedure which should be resorted to only to prevent *mutual induction.*

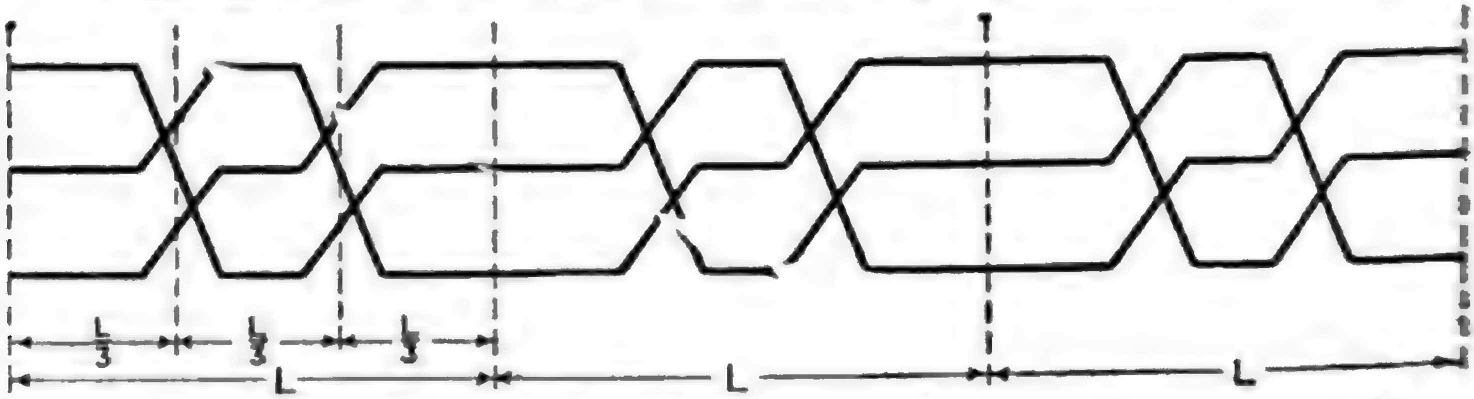


FIG. 2,680.—Transposition diagram of three phase, three wire line, with center arranged in a straight line.

The inductive effect of one line upon another is equal to the algebraic sum of the fluxes due to the different conductors of the first line, considered separately, which link the secondary line.

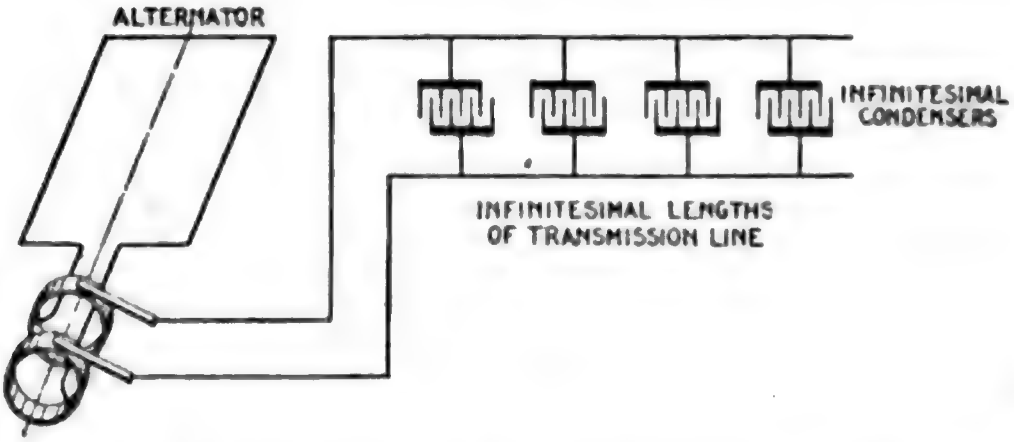
The effect of mutual induction is to induce surges in the line where a difference of frequency exists between the two currents, and to induce high electrostatic charges in lines carrying little or no current, such as telephone lines.

INDUCTANCE PER MILE OF THREE PHASE CIRCUIT

Size B. & S.	Diam. in inch.	Distance *d* in inches.	Self inductance L henrys.	Size B. & S.	Diam. in inch.	Distance *d* in inches.	Self inductance L henrys.
0000	.46	12	.00234	4	.204	12	.00280
		18	.00256			18	.00300
		24	.00270			24	.00315
		48	.00312			48	.00358
000	.41	12	.00241	5	.182	12	.00286
		18	.00262			18	.00307
		24	.00277			24	.00323
		48	.00318			48	.00356
00	.365	12	.00248	6	.162	12	.00291
		18	.00269			18	.00313
		24	.00285			24	.00329
		48	.00330			48	.00369
0	.325	12	.00254	7	.144	12	.00298
		18	.00276			18	.00310
		24	.00293			24	.00336
		48	.00331			48	.00377
1	.289	12	.00260	8	.128	12	.00303
		18	.00281			18	.00325
		24	.00308			24	.00341
		48	.00338			48	.00384
2	.258	12	.00267	9	.114	12	.00310
		18	.00288			18	.00332
		24	.00304			24	.00348
		48	.00314			48	.00389
3	.229	12	.00274	10	.102	12	.00318
		18	.00294			18	.00340
		24	.00310			24	.00355
		48	.00351			48	.00396

This effect may be nullified by separating the lines and by transposing the wires of one of the lines so that the effect produced in one section is opposed by that in another. Of two parallel lines consisting of two wires each, one may be transposed to neutralize the mutual inductance.

Fig. 2,678 shows this method. The length L′ should be an even factor of L so that to every section of the line transposed there corresponds an opposing section.



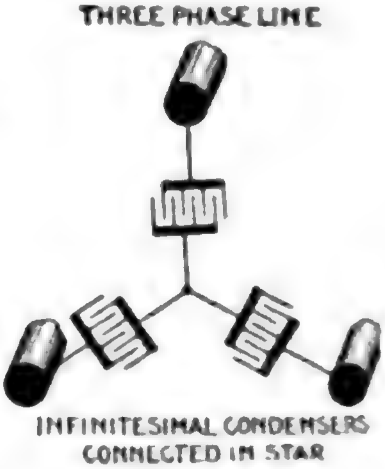


FIG. 2,681.—Capacity effect in single phase transmission line. The effect is the same as would be produced by shunting across the line at each point an infinitesimal condenser having a capacity equal to that of an infinitesimal length of circuit. For the purpose of calculating the charging current, a very simple and sufficiently accurate method is to determine the current taken by a condenser having a capacity equal to that of the entire line when charged to the pressure on the line at the generating end. The effect of capacity of the line is to reduce the pressure drop, that is, improve the regulation, and to decrease or increase the power loss depending on the load and power factor of the receiver.

FIG. 2,682.—Capacity effect in a three phase transmission line. It is the same as would be produced by shunting the line at each point by three infinitesimal condensers connected in star with the neutral point grounded, the capacity of each condenser being twice that of a condenser of infinitesimal length formed by any two of the wires. The effect of capacity on the regulation and efficiency of the line can be determined with sufficient accuracy in most cases by considering the line shunted at each end by three condensers connected in star, the capacity of each condenser being equal to that formed by any two wires of the line. An approximate value for the charging current per wire is the current required to charge a condenser, equal in capacity to that of any two of the wires, to the pressure at the generating end of the line between any one wire and the neutral point.

The self inductance of lines is readily calculated from the following formula:

$$L = .000558 \left\{ 2.303 \log (2\,A \div d) + .25 \right\} \text{ per mile of circuit}$$

where

L = inductance of a loop of a three phase circuit in henrys.

Note.—The inductance of a complete single phase circuit = $L \times 2 + \sqrt{3}$.

A = distance between wires;

d = diameter of wire.

Capacity.—In any given system of electrical conductors, a pressure difference between two of them corresponds to the presence of a quantity of electricity on each. With the same

CAPACITY IN MICRO-FARADS PER MILE OF CIRCUIT FOR THREE PHASE SYSTEM

Size B. & S.	Diam. in inch.	Distance A in inches.	Capacity C in micro-farads	Size B. & S.	Diam. in inch.	Distance A in inches.	Capacity C in micro-farads
0000	.46	12	.0226	4	.204	12	.01874
		18	.0204			18	.01726
		24	.01922			24	.01636
		48	.01474			48	.01452
000	.41	12	.0218	5	.182	12	.01830
		18	.01992			18	.01690
		24	.01876			24	.01602
		48	.01638			48	.01426
00	.365	12	.0124	6	.162	12	.01788
		18	.01946			18	.01654
		24	.01832			24	.01560
		48	.01604			48	.0140
0	.325	12	.02078	7	.144	12	.01746
		18	.01898			18	.01618
		24	.01642			24	.01538
		48	.01570			48	.01374
1	.289	12	.02022	8	.128	12	.01708
		18	.01952			18	.01586
		24	.01748			24	.01508
		48	.0154			48	.01350
2	.258	12	.01972	9	.114	12	.01660
		18	.01818			18	.01552
		24	.01710			24	.01478
		48	.01510			48	.01326
3	.229	12	.01938	10	.102	12	.01636
		18	.01766			18	.01522
		24	.01672			24	.01452
		48	.01480			48	.01304

charges, the difference of pressure may be varied by varying the geometrical arrangement and magnitudes and also by introducing various dielectrics. The constant connecting the charge and the resulting pressure is called the capacity of the system.

All circuits have a certain capacity, because each conductor acts like the plate of a condenser, and the insulating medium, acts as the dielectric. The capacity depends upon the insulation.

For a given grade of insulation, the capacity is proportional to the surface of the conductors, and universally to the distance between them.

A three phase three wire transmission line spaced at the corners of an equilateral triangle as regards capacity acts precisely as though the neutral line were situated at the center of the triangle.

The capacity of circuits is readily calculated by applying the following formulae:

$$C = \frac{38.83\, sc\, 10^{-3}}{\log\,(D \div d)} \text{ per mile, insulated cable with lead sheath;}$$

$$C = \frac{38.83 \times 10^{-3}}{\log\,(4h \div d)} \text{ per mile, single conductor with earth return;}$$

$$C = \frac{19.42 \times 10^{-3}}{\log\,(2\,A \div d)} \text{ per mile of parallel conductors forming metallic circuit;}$$

in which

C = Capacity in micro-farads; for a metallic circuit, C = capacity between wires;

sc = Specific inductive capacity of insulating material; = 1 for arc, and 2.25 to 3.7 for rubber;

D = Inside diameter of lead sheath;

d = Diameter of conductor;

h = Distance of conductors above ground;

A = Distance between wires.

Frequency.—The number of cycles per second, or the frequency, has a direct effect upon the inductance reactance in an alternating current circuit, as is plainly seen from the formula.

$$X_l = 2\pi f L$$

In the case of a transmission line alone; the lower frequencies are the more desirable, in that they tend to reduce the inductance drop and charging current. The inductance drop is proportional to the frequency.

The natural period of a line, with distributed inductance and capacity, is approximately given by

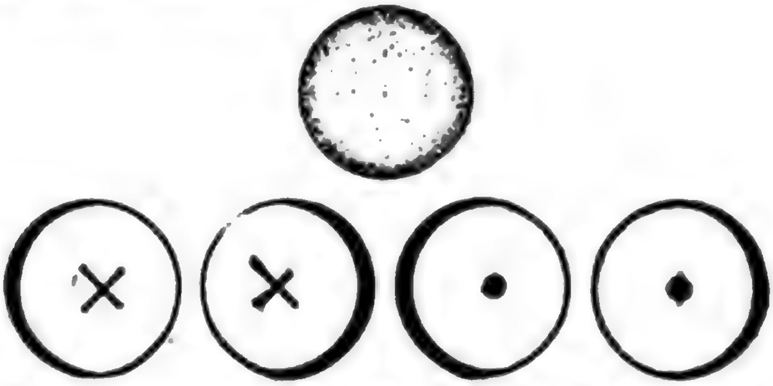
$$P = \frac{7{,}900}{\sqrt{LC}}$$

where L is the total inductance in millihenrys, and C, the total capacity in micro-farads. Accordingly some lower odd harmonic of the impressed frequency may be present which corresponds with the natural period of the line. When this obtains, oscillations of dangerous magnitude may occur. Such coincidences are less likely with the lower harmonics than with the higher.

Skin Effect.—The tendency of alternating current to confine itself to the *outer* portions of a conductor, instead of passing uniformly through the cross section, is called *skin effect*. The effect is proportional to the size of the conductor and the frequency.

Ques. What effect has "skin effect" on the current?

Ans. It is equivalent to an increase of ohmic resistance and therefore opposes the current.



FIGS. 2,683 to 2,687.—Skin effect and shield effect. Fig. 2,683, section of conductor illlustrating skin effect or tendency of the alternating current to distribute itself unequally through the cross section of a conductor as shown by the varied shading, which represents the current flowing most strongly in the outer portions of the conductor. For this reason it has been proposed to use hollow or flat instead of solid round conductors; however, with frequency not exceeding 100, the skin effect is negligibly small in copper conductors of the sizes usually employed. In figs. 2,684 and 2,685, or 2,686 and 2,687, if two adjacent conductors be carrying current in the same direction, concentration will occur on those parts of the two conductors remote from one another, and the nearer parts will have less current, that is to say, they will be **shielded**. In this case, the induction due to one conductor will exert its opposing effect to the greatest extent on those parts of the other conductor nearest to it; this effect decreasing the deeper the latter is penetrated. After crossing the current axis, the induction will still decrease in magnitude, but will now aid the current in the conductor. Hence, the effect of these two conductors on one another will make the current density more uniform than is the case where the two conductors adjacent to one another are carrying current in opposite directions, as in figs. 2,685 and 2,686, therefore, the resistance and the heating for a given current will be smaller. If the two return conductors be situated on the line passing through the center of the conductors just considered, the effect will be to still further concentrate the current; the distribution symmetry will be further disturbed, and the resistance of the conductor system increased. It is therefore difficult to say which of the two cases considered holds the advantage so far as increasing the resistance is concerned. The case, however, in which the phases are mixed has much the smaller reactive drop.

If the conductor be large, or the frequency high, the central portion of the conductor carries little if any current, hence the resistance is therefore greater for alternating current than for direct current.

Ques. For what condition may "skin effect" be neglected?

Ans. For frequencies of 60 or less, with conductors having a diameter not greater than 0000 B. & S. gauge.

Ques. How is the "skin effect" calculated for a given wire?

Ans. Its area in circular mils multiplied by the frequency, gives the ratio of the wire's ohmic resistance to its combined resistance.

> That is to say, the factor thus obtained multiplied by the resistance of the wire to direct current will give its combined resistance or resistance to alternating current.
>
> The following table gives these ratio factors for large conductors.

RATIO FACTOR FOR COMBINED RESISTANCE

Cir. mils. × frequency	Ratio factor	Cir. mils. × frequency	Ratio factor
10,000,000	1.00	70,000,000	1.13
20,000,000	1.01	80,000,000	1.17
30,000,000	1.03	90,000,000	1.20
40,000,000	1.05	100,000,000	1.25
50,000,000	1.08	125,000,000	1.34
60,000,000	1.10	150,000,000	1.43

Corona Effect.—When two wires, having a great difference of pressure are placed near each other, a certain phenomenon occurs, which is called *corona effect.* When the spacing or distance between the wires is small and the difference of pressure in the wires very great, a continuous passage of energy takes place through the dielectric or atmosphere, the amount of this energy may be an appreciable percentage of the power transmitted. Therefore in laying out high pressure transmission lines, this effect must be considered in the spacing of the wires.

Ques. How does the corona effect manifest itself?

Ans. It is visible at night as a bluish luminous envelope and audible as a hissing sound.

Ques. What is the critical voltage?

Ans. The voltage at which the corona effect loss takes place.

Ques. Upon what does the critical voltage depend?

Ans. Upon the radius of the wires, the spacing, and the atmospheric conditions.

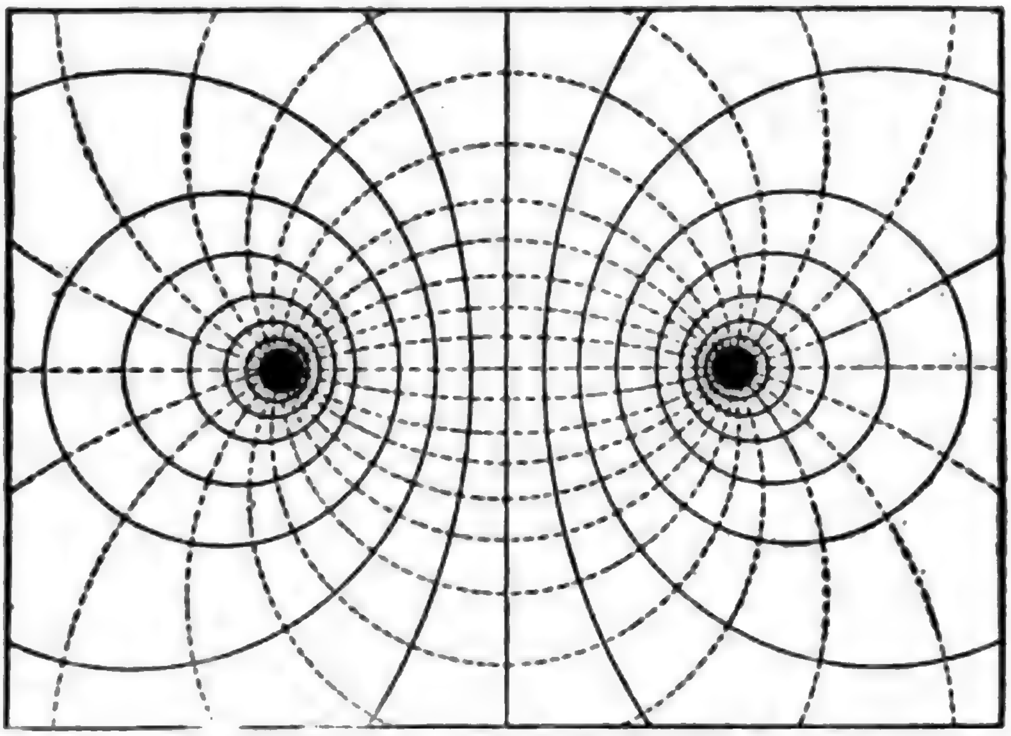


FIG. 2,688.—Electromagnetic and electrostatic fields surrounding the conductors of a transmission line. The electromagnetic field is represented by lines of magnetic force that surround the conductors in circles, (the solid lines), and the electrostatic field by (dotted) circles passing from conductor to conductor across at right angles to the magnetic circles. For any given size of wire and distance apart of wires there is a certain voltage at which the critical density or critical gradient is reached, where the air breaks down and luminosity begins—the critical voltage where corona manifests itself. At still higher voltages corona spreads to further distances from the conductor and a greater volume of air becomes luminous. Incidentally, it produces noise. Now to produce light requires power and to produce noise requires power. Air is broken down and is heated in breaking down, and to heat also requires power; therefore, as soon as corona forms, power is consumed or dissipated in its formation. When this phenomenon occurs on the conductors of an alternating current circuit a change takes place in relation to current and voltage. On the wires of an alternating current transmission line, at a voltage below that where corona forms —at a voltage where wires are not luminous—considerable current, more or less depending on voltage and length of wire, flows into the circuit as capacity current or charging current.

The critical voltage increases with both the diameter of the wires, and the spacing.

The losses due to corona effect increase very rapidly with increasing pressure beyond the critical voltage.

The magnitude of the losses as well as the critical voltage is affected, by atmospheric conditions, hence they probably vary with the particular locality, and the season of the year. Therefore, for a given locality, a voltage which is normally below the critical point, may at times be above it, depending upon changes in the weather.

Such elements as smoke, fog, moisture, or other particles (dust, snow, etc.) floating in the air, increase the losses; rain, however, apparently has no appreciable effect upon the losses. It follows then that in the design of a transmission line, the atmospheric conditions of the particular locality through which the line passes should be considered.

Ques. How should live wires be spaced?

Ans. They should be so spaced as to lessen the tendency to leakage and to prevent the wires swinging together or against towers. The spacing should be only sufficient for safety, since increased spacing increases the self-induction of the line, and while it lessens the capacity, it does so only in a slight degree.

The following spacing is in accordance with average practice.

SPACING FOR VARIOUS VOLTAGES

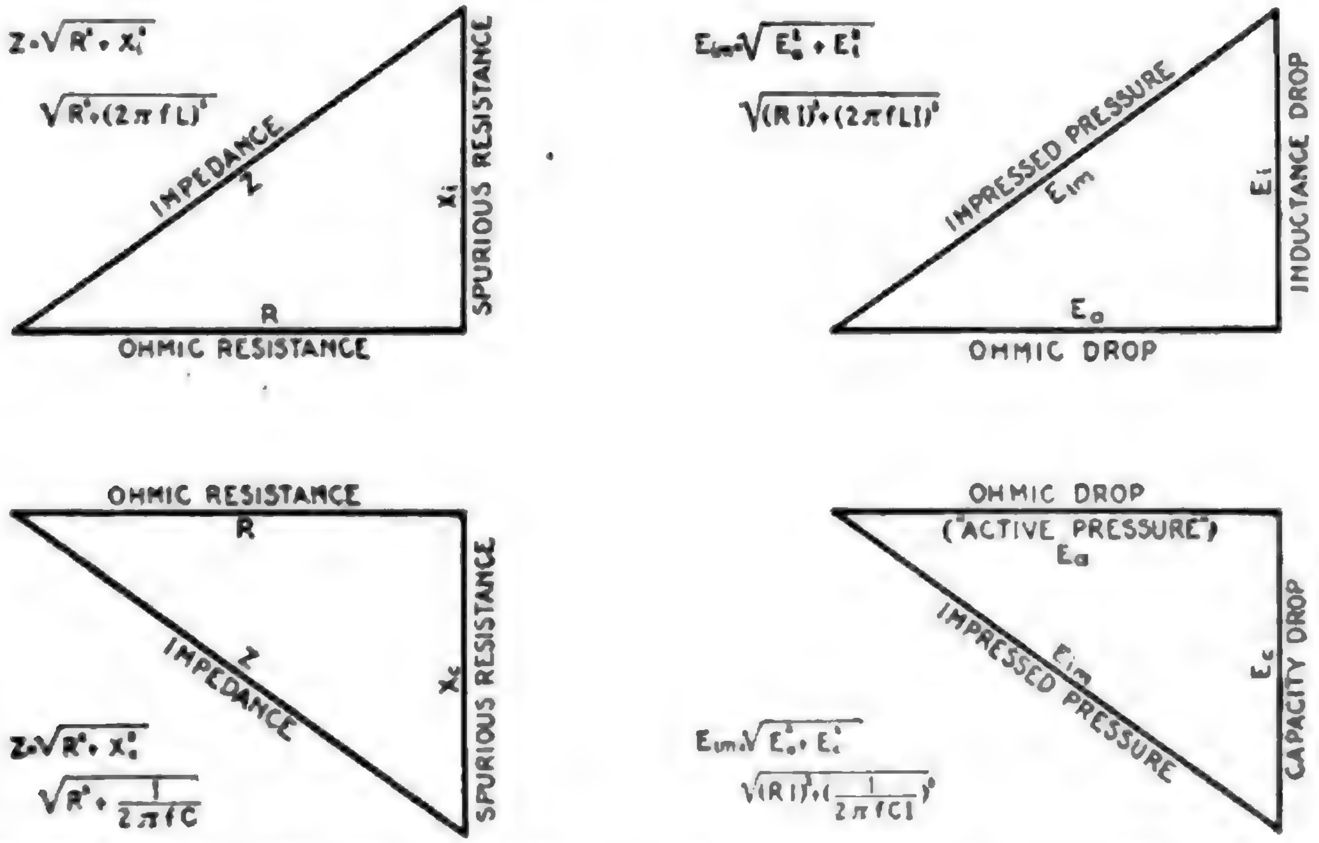
Volts	Spacing	Volts	Spacing	Volts	Spacing
5,000	28 ins.	45,000	60 ins.	90,000	96 ins.
15,000	40 ins.	60,000	60 ins.	105,000	108 ins.
30,000	48 ins.	75,000	84 ins.	120,000	120 ins.

Resistance of Wires.—For quick calculation the following method of obtaining the resistance (approximately) of wires will be found convenient:

1,000 feet No. 10 B. & S. wire, which is about .1 inch in diameter (.1019), has a resistance of one ohm, at a temperature of 68° F. and weighs 31.4 pounds. A wire three sizes larger, that is No. 7, has twice the cross section and therefore one-half the resistance. A wire three sizes smaller than No. 10, that is No. 13, has one-half the cross section and therefore twice the resistance.

Thus, starting with No. 10, any number three sizes larger will double the cross sectional area and any wire three sizes smaller will halve the cross sectional area of the preceding wire. This is true to the extreme limits of the table, so that the area, weight and resistance of any wire may be at once calculated to a close approximation from this rule, intermediate sizes being obtained by interpolation.

For alternating current, the combined resistance, that is, the total resistance, including skin effect, is obtained by multiplying the resistance, as found above by the "ratio factor" (see table page 1,894).


$Z=\sqrt{R^2+X_i^2}$
$\sqrt{R^2+(2\pi fL)^2}$
IMPEDANCE
Z
X_i
SPURIOUS RESISTANCE
R
OHMIC RESISTANCE
$E_{im}=\sqrt{E_o^2+E_i^2}$
$\sqrt{(RI)^2+(2\pi fLI)^2}$
IMPRESSED PRESSURE
E_{im}
E_i
INDUCTANCE DROP
E_o
OHMIC DROP
OHMIC RESISTANCE
R
IMPEDANCE
Z
X_c
SPURIOUS RESISTANCE
$Z=\sqrt{R^2+X_c^2}$
$\sqrt{R^2+\frac{1}{2\pi fC}}$
OHMIC DROP
("ACTIVE PRESSURE")
E_o
IMPRESSED PRESSURE
E_{im}
E_c
CAPACITY DROP
$E_{im}=\sqrt{E_o^2+E_c^2}$
$\sqrt{(RI)^2+(\frac{1}{2\pi fCI})^2}$

FIGS. 2,689 to 2,692.—Triangles for obtaining graphically, impedance, impressed pressure, etc., in alternating current circuits. For a full explanation of this method the reader is referred to Guide 5, Chapter XLVII or Alternating Current Diagrams. A thorough study of this chapter is recommended.

Impedance.—*The total opposition to the flow of electricity in an alternating current circuit*, or the impedance may be resolved into two components representing the ohmic resistance and the spurious resistance; these components have a phase difference of 90°, and they may be represented graphically by the two legs of a right angle triangle, of which the hypothenuse represents the impedance.

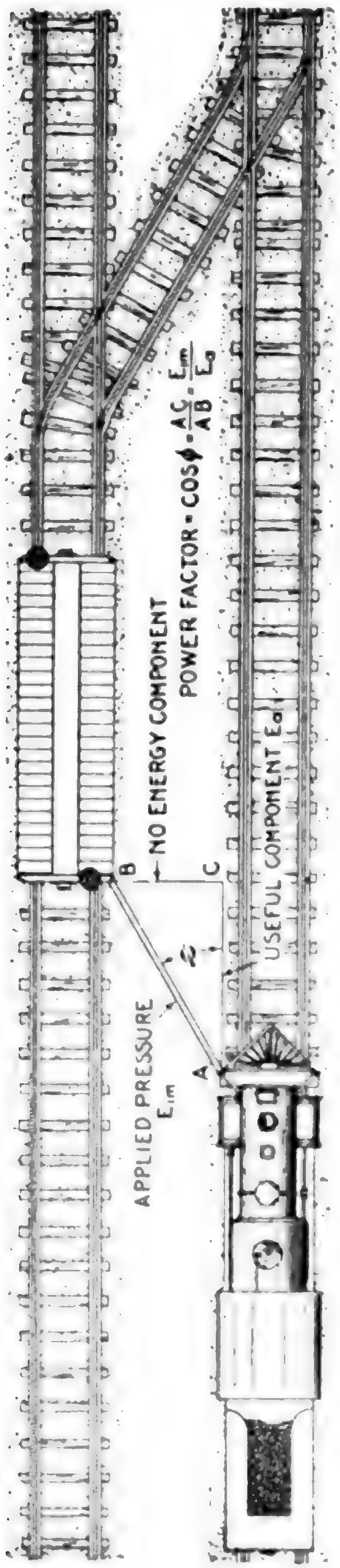


FIG. 2,693.—Mechanical analogy of power factor, as exemplified by a locomotive "poling" a car off a siding. The car and locomotive are shown moving in parallel directions, and the pole AB, inclined at an angle ϕ. Now, if the length of AB be taken to represent the pressure exerted on the pole by the locomotive, then the imaginary lines AC and BC, drawn respectively parallel and at right angles to the direction of motion will represent respectively the useful and no energy (wattless) components; that is to say, if the pressure AB be applied to the car at an angle ϕ, only part of it, AC, is useful in propelling the car, the other component, BC, being wasted in tending to push the car off the track at right angles to the rails, being resisted by the flanges of the outer wheels.

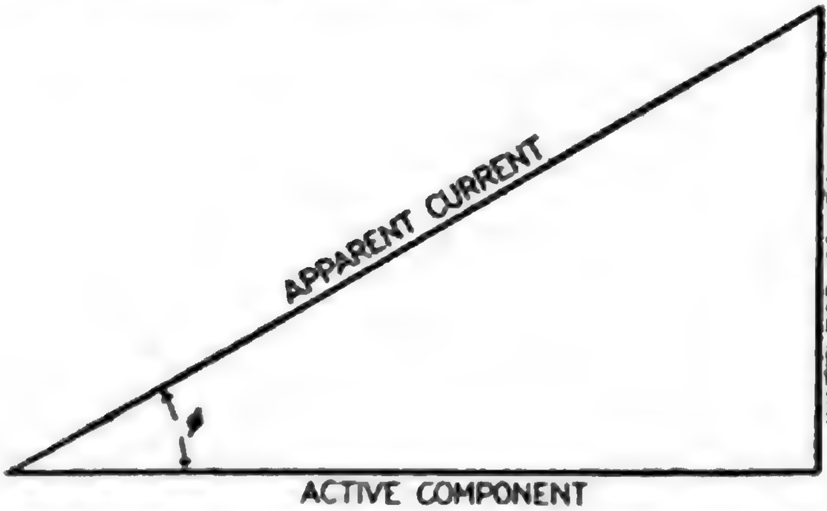
Similarly, the **volts lost** or "drop" in an alternating circuit may be resolved into two components representing respectively

1. The loss due to resistance.
2. The loss due to reactance.

These components have a phase difference of 90° and are represented graphically similar to the impedance components. This has been explained at considerable length in Chapter XLVII (Guide V).

Power Factor.—When the current falls out of step with the pressure, as on inductive loads, the power factor becomes less than unity, and the effect is to increase the current required for a given load. Accordingly, this must be considered in calculating the size of the wires. As has been explained, the current flowing in an alternating current circuit, as measured by an ammeter, can be resolved into two components, representing respectively the *active component* and the *wattless component* or idle current. These are graphically represented by the two legs of a right triangle, of which the hypothenuse represents the current measured by the ammeter.

This *apparent* current, as is evident from the triangle, exceeds the *active* current and lags behind the pressure by an amount represented by the angle ϕ between the hypothenuse and leg representing the energy current as shown in fig. 2,694.



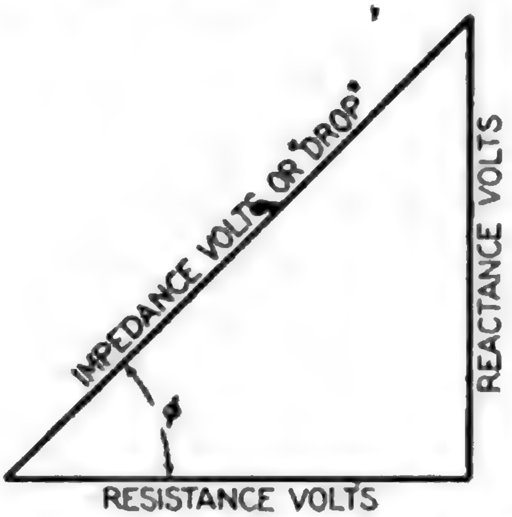


FIG. 2,694.—Diagram showing that the apparent current is more than the active current, the excess depending upon the angle of phase difference.

FIG. 2,695.—Diagram showing components of impedance volts. Compare this diagram with figs. 2,689 and 2,671, and note that the term "reactance" is the difference between the inductance drop and the capacity drop if the circuit contain capacity, for instance, if inductance drop be 10 volts and capacity drop be 7 volts then reactance $10-7=3$ volts.

Ques. What determines the heating of the wires on alternating current circuits with inductive loads?

Ans. The apparent current, as represented by the hypothenuse of the triangle in fig. 2,694.

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Ques. How is the apparent current obtained?

Ans. Divide the true watts by the product of the power factor multiplied by the voltage.

Example.—A certain circuit supplies 20 kw. to motors at 220 volts and .8 power factor. What is the apparent current?

$$\text{Apparent Current} = \frac{\text{true watts}}{\text{power factor} \times \text{volts}} = \frac{20,000}{.8 \times 220} = 113.6 \text{ amperes}$$

Ques. What else, besides power factor, should be considered in making wire calculations for motor circuits?

Ans. The efficiency of the motor, and the heavy starting current.

The product of the efficiency of the motor multiplied by the power factor gives the *apparant efficiency*, which governs the size of the wires, apparatus, etc., necessary to feed the motors.

Allowance should be made for the heavy starting current required for some motors to avoid undue drop.

TABLE OF APPROXIMATE AMPERES PER TERMINAL FOR INDUCTION MOTORS

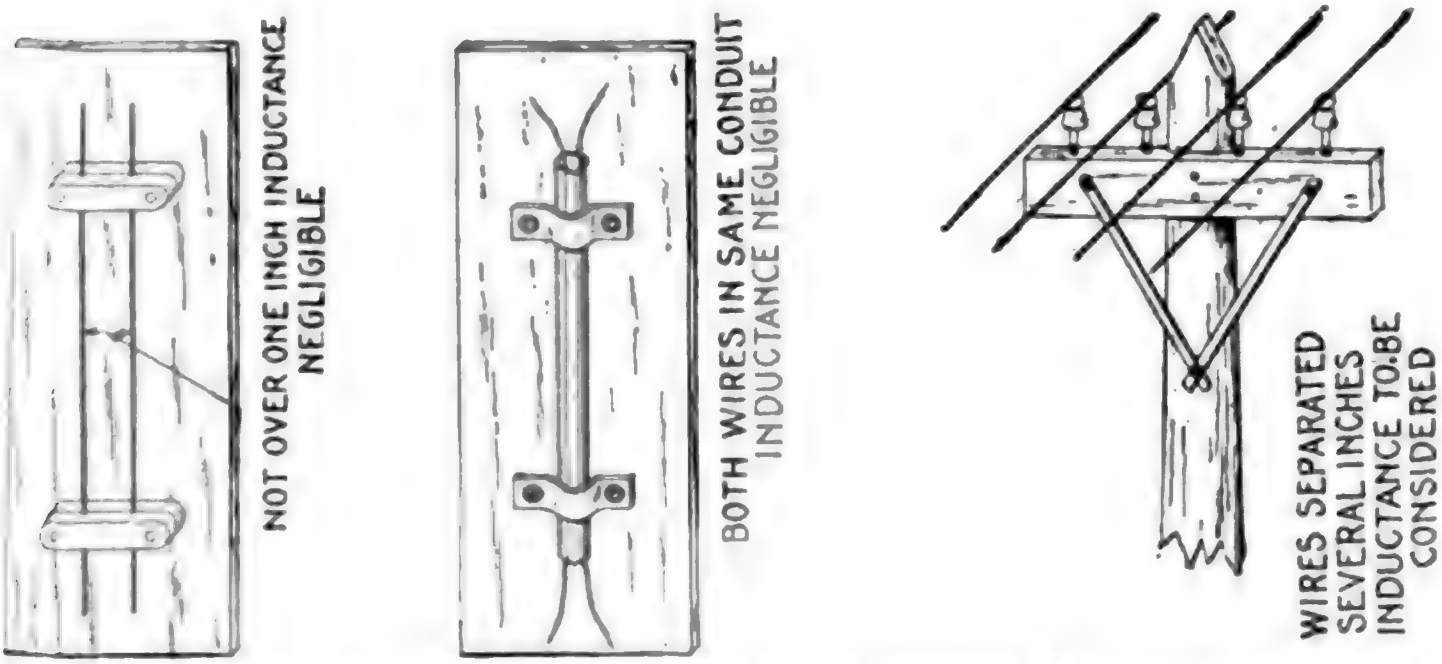
Horse power	Single phase			Two phase four wire			Three phase three wire			
	110 volts	220 volts	440 volts	110 volts	220 volts	440 volts	110 volts	220 volts	440 volts	550 volts
.5	6.6	3.4	1.8	3.3	1.7	.9	3.7	1.8	1	
1	14	7	3.5	6.4	3.2	1.6	7.4	3.7	1.9	
2	24	12	6	11	5.7	2.9	13	6.6	3.3	2.5
3	34	17	8.5	16	8.1	4.1	19	9.3	4.7	3.5
4	52	26	13	26	13	6.5	30	15	7.5	6
5	74	37	18.5	38	19	9.5	44	22	11	9
10	94	47	23.5	44	22	11	50	25	12.5	11
15	....	....	....	66	33	16.5	76	38	19	16
20	....	....	....	88	44	22	102	51	25.5	22
25	....	....	....	111	55	28	129	64	32	25
30	....	....	....	134	67	33.5	154	77	38.5	32
40	....	....	....	178	89	44.5	204	107	53.5	44
50	....	....	....	204	102	51	236	118	59	52
75	....	....	....	308	154	77	356	178	89	77
100	....	....	....	408	204	102	472	236	118	100

Ques. What are the usual power factors encountered on commercial circuits?

Ans. A mixed load of incandescent lamps and induction motors will have a power factor of from .8 to .85; induction motors above .8 to .85; incandescent and Nernst lamps .98; arc lamps, .85.

Wire Calculations.—In the calculation of alternating current circuits, the two chief factors which make the computation different from that for direct current circuits, is *induction* and *power factor*. The first depends on the frequency, and physical condition of the circuit, and the second upon the character of the load.

Ques. Under what conditions may inductance be neglected?


NOT OVER ONE INCH INDUCTANCE NEGLIGIBLE
BOTH WIRES IN SAME CONDUIT INDUCTANCE NEGLIGIBLE
WIRES SEPARATED SEVERAL INCHES INDUCTANCE TO BE CONSIDERED

Figs. 2,696 to 2,698.—Example of wiring showing where inductance is negligible, and where it must be considered in wire calculations.

Ans. In cases where the wires of a circuit are not spaced ver an inch apart, or in conduit work, where both wires are in he same conduit.

Under these conditions the calculation is the same as for direct current after making proper allowance for power factor.

Ques. Under what conditions must induction be onsidered?

Ans. On exposed circuits with wires separated several inches, articularly in the case of large wires.

Sizes of Wire.—The size of wire for any alternating circuit may be determined by slightly modifying the formula used in direct current work, and which, as derived in Guide No. 4, page 748, is

$$\text{circular mils} = \frac{\text{amperes} \times \text{feet} \times 21.6}{\text{drop}} \ldots\ldots\ldots \quad (1)$$

The quantity 21.6, is twice the resistance (10.8) of a foot of copper wire one mil in diameter (*mil foot*). This resistance (10.8) is multiplied by 2, giving the quantity 21.6, because the length of a circuit, or feet in the formula, is given as the "run" or distance one way, that is, one-half the total length of wire in the circuit, must be multiplied by 2 to get the total drop, viz.:

$$\text{circular mils} = \frac{\text{amperes} \times \text{feet} \times 10.8 \times 2}{\text{drop}} = \frac{\text{amperes} \times \text{feet} \times 21.6}{\text{drop}}$$

It is sometimes however convenient to make the calculation in terms of watts. Formula (1) may be modified for such calculation.

In modifying the formula, the "drop" should be expressed in percentage instead of actual volts lost, that is, instead of the difference in pressure between the beginning and the end of the circuit.

In any circuit the loss in percentage, or

$$\%\ \text{loss} = \frac{\text{drop}}{\text{impressed pressure}} \times 100$$

from which

$$\text{drop} = \frac{\%\ \text{loss} \times \text{impressed pressure}}{100} \ldots \quad (2)$$

Substituting equation (2) in equation (1)

$$\text{circular mils} = \frac{\text{amperes} \times \text{feet} \times 21.6}{\dfrac{\%\ \text{loss} \times \text{imp. pressure}}{100}}$$

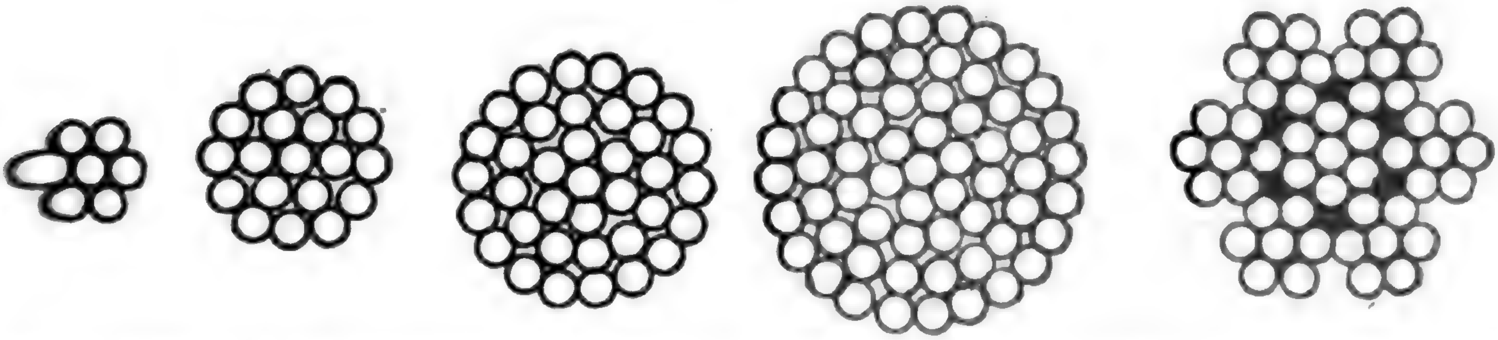
$$= \frac{\text{amperes} \times \text{feet} \times 2{,}160}{\%\ \text{loss} \times \text{imp. pressure}} \ldots\ldots \quad (3)$$

Equation (3) is modified for calculation in terms of watts as follows: The power in watts is equal to the *applied voltage* multiplied by the current, that is to say, the power is equal to the *volts at the consumer's end of the circuit* multiplied by the current, or simply

$$\text{watts} = \text{volts} \times \text{amperes}$$

from which

$$\text{amperes} = \frac{\text{watts}}{\text{volts}} \quad . \quad . \quad . \quad . \qquad (4)$$



Figs. 2,699 to 2,703.—Stranded copper cables. For conductors of large areas and in the smaller sizes where extra flexibility is required it becomes necessary to employ stranded cables made by grouping a number of wires together in either concentric or rope form. The concentric cable as here illustrated is formed by grouping six wires around a central wire thereby forming a seven wire cable. The next step is the application in a reverse direction of another layer of 12 wires and a nineteen wire cable is produced. This is again increased by a third layer of eighteen wires for a 37 wire cable and a fourth layer of 24 wires for a 61 wire cable. Successive layers, each containing 6 more wires than that preceding, may be applied until the desired capacity is obtained. The cuts show sectional views of concentric cables each formed from No. 10 B. & S. gauge wires.

Substituting this value for the current in equation (3) and remembering that the pressure taken is the volts at the consumer's end of the line

$$\text{circular mils} = \frac{\dfrac{\text{watts}}{\text{volts}} \times \text{feet} \times 2{,}160}{\%\ \text{loss} \times \text{volts}}$$

$$= \frac{\text{watts} \times \text{feet} \times 2{,}160}{\%\ \text{loss} \times \text{volts}^2} \quad . \quad . \qquad (5)$$

This formula (5) applies to a direct current two wire circuit, and to adapt it to any alternating current circuit it is only necessary to use the letter M instead of the number 2,160, thus

$$\text{circular mils} = \frac{\text{watts} \times \text{feet} \times M}{\%\ \text{loss} \times \text{volts}^2} \quad . \quad . \quad . \quad (6)$$

in which M is a coefficient which has various values according to the kind of circuit and value of the power factor. These values are given in the following table:

VALUES OF M

SYSTEM	POWER FACTOR									
	1.00	.98	.95	.90	.85	.80	.75	.70	.65	.60
Single phase	2,160	2,249	2,400	2,660	3,000	3,380	3,840	4,400	5,112	6,000
Two phase (4 wire)	1,080	1,125	1,200	1,330	1,500	1,690	1,920	2,200	2,556	3,000
Three phase (3 wire)	1,080	1,125	1,200	1,330	1,500	1,690	1,920	2,200	2,556	3,000

NOTE.—The above table is calculated as follows: For **single phase** M = 2,160 ÷ power factor² × 100; for **two phase** four wire, or three phase three wire, M = ½ (2,160 ÷ power factor²) 100. Thus the value of M for a single phase line with power factor .95 = 2,160 ÷ .95² × 100 = 2,400.

It must be evident that when 2,160 is taken as the value of M, formula (6) applies to a two wire direct current circuit and also to a single phase alternating current circuit when the power factor is unity.

In the table the value of M for any particular power factor is found by dividing 2,160 by the square of that power factor for single phase and twice the square of the power factor for two phase and three phase.

Ques. For a given load and voltage how do the wires of a single and two phase system compare in size and weight, the power factor being the same in each case?

Ans. Since the two phase system is virtually two single phase systems, the four wires of the two phase systems are half the size of the two wires of the single phase system, and accordingly, the weight is the same for either system.

VALUES OF T

SYSTEM	POWER FACTOR				
	1.00	.98	.90	.80	.70
Single phase	1.00	.98	.90	.80	.70
Two phase, 4 wire.....	2.00	1.96	1.80	1.60	1.40
Three phase, 3 wires...	1.73	1.70	1.55	1.38	1.21

NOTE.—This table is for finding the value of the current in line, using the formula $= W \div (E \times T)$, in which $I =$ current in line; $E =$ voltage between main conductors at ceiving or consumers' end; $W =$ watts. For instance, what is the current in a two phase line ansmitting 1,000 watts at 550 volts, power factor .80? $I = 1{,}000 \div (550 \times 1.60) = 1.13$.

Ques. Since there is no saving in copper in using two hases, what advantage has the two phase system over the ne phase system?

Ans. It is more desirable on power circuits, because two ase motors are self-starting.

That is to say, the rotating magnetic field that can be produced by a two phase current, permits an induction motor to start without being equipped with any special phase splitting devices which are necessary on single phase motors, because the oscillating field produced by a single phase current does not produce any torque on a squirrel cage armature at rest.

Ques. For equal working conditions, what is the comparison between the single, two and three phase system as to size and weight of wires?

Ans. Each wire of the three phase system is half the size of one of the wires of the single phase system, hence the weight of copper required for the three phase system is 75% of that required for the single phase system. Since in the two phase system half of the load is carried by each phase, each wire of the three phase system is the same size as one of the wires of the two phase system, hence, the copper required by the three phase system is 75% of that required by the two phase system.

MISCELLANEOUS FORMULÆ FOR COPPER WIRES

Diameter squared = circular mils
Circular mils × .7854 = square mils
.000003027 × circular mils = pounds per foot
.003027 × circular mils = pounds per 1,000 feet
.0159847 × circular mils = pounds per mile
.003879 × square mils = pounds per 1,000 feet
.33033 ÷ circular mils = feet per pound
.0000002924 × circular mils = pounds per ohm
.342 ÷ circular mils = ohms per pound
.096585 × circular mils = feet per ohm
10.353568 ÷ circular mils = ohms per foot

Breaking weight of wire ÷ area = breaking weight per square inch.

Breaking weight per square inch × area = breaking weight of wire.

The weight of copper wire is $1\frac{1}{7}$ times the weight of iron wire of same diameter.

EXAMPLE.—What size wires must be used on a single phase circuit 2,000 feet in length to supply 30 kw. at 220 volts with loss of 4%, the power factor being .9?

The formula for circular mils is

$$\text{circular mils} = \frac{\text{watts} \times \text{feet} \times \text{M}}{\%\ \text{loss} \times \text{volts}^2} \quad . \quad . \quad . \quad . \quad (1)$$

Substituting the given values and the proper value of M from the table, in (1)

$$\text{circular mils} = \frac{30{,}000 \times 2{,}000 \times 2{,}660}{4 \times 220^2} = 82{,}438$$

Referring to the accompanying table of the properties of copper wire, the nearest *larger* size wire is No. 1 B. & S. gauge having an area of 83,690 circular mils.

TABLE OF THE PROPERTIES OF COPPER WIRE

Giving weights, length and resistances of wires of Matthiessen's Standard Conductivity for both B. & S. G. (Brown & Sharpe Gauge) and B. W. G. (Birmingham Wire Gauge) from Transactions October 1903, of the American Institute of Electrical Engineers.

Gauges.	To the nearest fourth significent digit.			Weight. Lbs. per 1,000 feet.	Length.	Resistance.
		Diameter.	Area.		Feet per lb.	Ohms per 1,000 feet.
B. & S.	B. W. G.	Inches.	Circular mils.			@ 68° F.
0000		0.460	211,600	640.5	1.561	.04893
	0000	0.454	206,100	623.9	1.603	.05023
	000	0.425	180,600	546.8	1.829	.05732
000		0.4096	167,800	508.0	1.969	.06170
	00	0.380	144,400	437.1	2.288	.07170
00		0.3648	133,100	402.8	2.482	.07780
	0	0.340	115,600	349.9	2.858	.08957
0		0.3249	105,500	319.5	3.130	.09811
	1	0.3000	90,000	272.4	3.671	.1150
1		0.2893	83,690	253.3	3.947	.1237
	2	0.2840	80,660	244.1	4.096	.1284
	3	0.2590	67,080	203.1	4.925	.1543
2		0.2576	66,370	200.9	4.977	.1560
	4	0.2380	56,640	171.5	5,832	.1828
3		0.2294	52,630	159.3	6.276	.1967
	5	0.2200	48,400	146.5	6.826	.2139
4		0.2043	41,740	126.4	7.914	.2480
	6	0.2030	41,210	124.7	8.017	.2513

TABLE OF THE PROPERTIES OF COPPER WIRE

(Continued)

Gauges. To the nearest fourth significent digit.				Weight. Lbs. per 1,000 feet.	Length.	Resistance.
		Diameter.	Area.		Feet per lb.	Ohms per 1,000 feet.
B. & S.	B. W. G.	Inches.	Circular mils			@ 68° F.
5		0.1819	33,100	100.2	9.980	.3128
	7	0.1800	32,400	98.08	10.20	.3196
	8	0.1650	27,230	82.41	12.13	.3803
6		0.1620	26,250	79.46	12.58	.3944
	9	0.1480	21,900	66.30	15.08	.4727
7		0.1443	20,820	63.02	15.87	.4973
	10	0.1340	17,960	54.35	18.40	.5766
8		0.1285	16,510	49.98	20.01	.6271
	11	0.1200	14,400	43.59	22.94	.7190
9		0.1144	13,090	39.63	25.23	.7908
	12	0.1090	11,880	35.96	27.81	.8715
10		0.1019	10,380	31.43	31.82	.9972
	13	0.0950	9,025	27.32	36.60	1.147
11		0.09074	8,234	24.93	40.12	1.257
	14	0.08300	6,889	20.85	47.95	1.503
12		0.08081	6,530	19.77	50.59	1.586
	15	0.07200	5,184	15.69	63.73	1.997
13		0.07196	5,178	15.68	63.79	1.999
	16	0.06500	4,225	12.79	78.19	2.451
14		0.06408	4,107	12.43	80.44	2.521
	17	0.0580	3,364	10.18	98.23	3.078
15		0.05707	3,257	9.858	101.4	3.179
16		0.05082	2,583	7.818	127.9	4.009
	18	0.04900	2,401	7.268	137.6	4.312
17		0.045260	2,048	6.200	161.3	5.055
	19	0.042000	1,764	5.340	187.3	5.870
18		0.040300	1,624	4.917	203.4	6.374
19		0.035890	1,288	3.899	256.5	8.038
	20	0.035000	1,225	3.708	269.7	8.452
	21	0.032000	1,024	3.100	322.6	10.11
20		0.031960	1,022	3.092	323.4	10.14
21		0.028460	810.1	2.452	407.8	12.78
	22	0.028000	784.0	2.373	421.4	13.21
22		0.025350	642.4	1.945	514.2	16.12
	23	0.025000	625.0	1.892	528.6	16.57

TABLE OF THE PROPERTIES OF COPPER WIRE

(Concluded)

Gauges. B. & S.	B. W. G.	To the nearest fourth significent digit. Diameter. Inches.	Area. Circular mils	Weight. Lbs. per 1,000 feet.	Length. Feet per lb.	Resistance. Ohms per 1,000 feet. @ 68° F.
23		0.022570	509.5	1.542	648.4	20.32
	24	0.022000	484.0	1.465	682.6	21.39
24		0.020100	404.0	1.223	817.6	25.63
	25	0.020000	400.0	1.211	825.9	25.88
	26	0.018000	324.0	.9808	1,020	31.96
25		0.017900	320.4	.9699	1,031	32.31
	27	0.016000	256.0	.7749	1,290	40.45
26		0.015940	254.1	.7692	1,300	40.75
27		0.014200	201.5	.6100	1,639	51.38
	28	0.014000	196.0	.5933	1,685	52.83
	29	0.013000	169.0	.5116	1,955	61.27
28		0.012640	159.8	.4837	2,067	64.79
	30	0.012000	144.0	.4359	2,294	71.90
29		0.011260	126.7	.3836	2,607	81.70
30		0.010030	100.5	.3042	3,287	103.0
	31	0.010000	100.0	.3027	3,304	103.5
	32	0.009000	81.0	.2452	4,078	127.8
31		0.008928	79.70	.2413	4,145	129.9
	33	0.008000	64.0	.1937	5,162	161.8
32		0.007950	63.21	.1913	5,227	163.8
33		0.007080	50.13	.1517	6,591	206.6
	34	0.007000	49.0	.1483	6,742	211.3
34		0.006305	39.75	.1203	8,311	260.5
35		0.005615	31.52	.09543	10,480	328.4
36	35	0.005000	25.0	.07568	13,210	414.2
37		0.004453	19.83	.06001	16,660	522.2
	36	0.004000	16.	.04843	20,650	647.1
38		0.003965	15.72	.04759	21,010	658.5
39		0.003531	12.47	.03774	26,500	830.4
40		0.003145	9.888	.02993	33,410	1047.

Drop.—In order to determine the drop or volts lost in the line, the following formula may be used

$$\text{drop} = \frac{\% \text{ loss} \times \text{volts}}{100} \times S \quad . \quad . \quad . \quad (1)$$

in which the % loss is a percentage of the applied power, that is, the power delivered to the consumer and not a percentage of the power at the alternator. "Volts" is the pressure at the consumer's end of the circuit.

VALUE OF "S" FOR 60 CYCLES

Size of wire B. & S. gauge	Area in circular mils.	.98 power factor					.90 power factor					.80 power factor					.70 power factor				
		Spacing of conductors					Spacing of conductors					Spacing of conductors					Spacing of conductors				
		1″	3″	6″	12″	24″	1″	3″	6″	12″	24″	1″	3″	6″	12″	24″	1″	3″	6″	12″	24″
500,000	500,000	1.21	1.45	1.61	1.77	1.92	1.32	1.80	2.11	2.44	2.75	1.27	1.89	2.25	2.64	3.03	1.14	1.72	2.12	2.53	2.93
300,000	300,000	1.15	1.29	1.38	1.48	1.57	1.19	1.47	1.66	1.84	2.02	1.11	1.46	1.68	1.90	2.12	1.00	1.33	1.56	1.78	2.01
0,000	211,600	1.12	1.22	1.28	1.34	1.41	1.13	1.33	1.45	1.58	1.63	1.03	1.27	1.43	1.58	1.75	1.00	1.14	1.29	1.45	1.60
000	167,800	1.09	1.18	1.22	1.28	1.29	1.08	1.23	1.33	1.44	1.53	1.00	1.16	1.28	1.41	.153	1.00	1.02	1.15	1.28	1.50
00	133,100	1.07	1.14	1.18	1.21	1.25	1.03	1.16	1.24	1.32	1.40	1.00	1.07	1.17	1.27	1.36	1.00	1.00	1.03	1.13	1.21
0	105,500	1.05	1.10	1.14	1.17	1.20	1.00	1.09	1.16	1.22	1.28	1.00	1.00	1.07	1.15	1.22	1.00	1.00	1.00	1.01	1.09
1	83,690	1.04	1.08	1.10	1.13	1.15	1.00	1.05	1.09	1.14	1.19	1.00	1.00	1.00	1.05	1.11	1.00	1.00	1.00	1.00	1.00
2	66,370	1.02	1.05	1.08	1.10	1.12	1.00	1.00	1.04	1.08	1.12	1.00	1.00	1.00	1.00	1.02	1.00	1.00	1.00	1.00	1.00
3	52,630	1.02	1.04	1.06	1.07	1.09	1.00	1.00	1.00	1.03	1.06	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
4	41,740	1.00	1.02	1.03	1.04	1.07	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
5	33,100																				
6	26,250	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
7	20,820																				
8	16,510	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
9	13,090																				
10	10,380																				

The coefficient S has various values as given in the accompanying tables. As will be seen from the table, the value of S to be used depends upon the size of wire, spacing, power factor and frequency.

These values are accurate enough for all practical purposes, and may be used for distances of 20 miles or less and for voltages up to 25,000.

The capacity effect on very long high voltage lines, makes this method of determining the drop somewhat inaccurate beyond the limits above mentioned.

VALUE OF "S" FOR 25 CYCLES

Size of wire B. & S. gauge	Area in circular mils.	.98 power factor					.90 power factor					.80 power factor					.70 power factor				
		Spacing of conductors					Spacing of conductors					Spacing of conductors					Spacing of conductors				
		1″	2″	6″	12″	24″	1″	3″	6″	12″	24″	1″	3″	6″	12″	24″	1″	3″	6″	12″	24″
500,000	500,000	1.01	1.17	1.23	1.29	1.36	1.02	1.22	1.35	1.43	1.61	1.00	1.15	1.30	1.47	1.62	1.00	1.00	1.16	1.33	1.49
300,000	200,000	1.04	1.10	1.13	1.18	1.21	1.00	1.08	1.16	1.25	1.31	1.00	1.00	1.09	1.16	1.25	1.00	1.00	1.00	1.02	1.12
0,000	211,600	1.03	1.07	1.09	1.11	1.14	1.00	1.02	1.07	1.13	1.15	1.00	1.00	1.00	1.03	1.10	1.00	1.00	1.00	1.00	1.00
000	167,800	1.00	1.05	1.06	1.09	1.10	1.00	1.00	1.02	1.07	1.11	1.00	1.00	1.00	1.00	1.01	1.00	1.00	1.00	1.00	1.00
00	133,100	1.00	1.03	1.05	1.06	1.08	1.00	1.00	1.00	1.02	1.05	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
0	105,500	1.00	1.01	1.02	1.03	1.04	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1 2 3	83,690 66,370 52,630	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
4 5 6	41,740 33,100 26,250	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
7 8 9 10	20,820 16,510 13,090 10,380	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

EXAMPLE.—A circuit supplying current at 440 volts, 60 frequency, with 5% loss and .8 power factor is composed of No. 2 B. & S. gauge wires spaced one foot apart. What is the drop in the line?

According to the formula

$$\text{drop} = \frac{\%\ \text{loss} \times \text{volts}}{100} \times S$$

Substituting the given values, and value of S as obtained from the table for frequency 60

$$\text{drop} = \frac{5 \times 440}{100} \times 1 = 22 \text{ volts}$$

Current.—As has been stated, the effect of power factor less than unity, is to increase the current; hence, in inductive circuit calculations, the first step is to determine the current flowing in circuit. This is done as follows:

$$\text{current} = \frac{\text{apparent load}}{\text{volts}} \quad . \quad . \quad . \qquad (1$$

and

$$\text{apparent load} = \frac{\text{watts}}{\text{power factor}} \quad . \quad . \quad . \qquad (2$$

Substituting (2) in (1)

$$\text{current} = \frac{\dfrac{\text{watts}}{\text{power factor}}}{\text{volts}} = \frac{\text{watts}}{\text{power factor} \times \text{volts}} \quad . \qquad (3$$

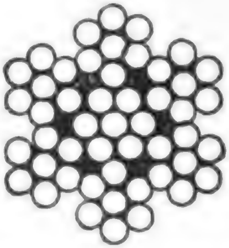


FIG. 2,704.—Rope type of stranded copper cable which is used when a high degree of flexib is required. The construction of this cable is the stranding together of seven gro each containing seven wires and producing a total of 49 wires. In cases when a gre carrying capacity is desired than can be obtained through the use of the 7 × 7 or 49 w cable, the number of groups is increased to nineteen thereby making a total of 133 w (19 × 7).

EXAMPLE.—A 50 horse power 440 volt motor has a full load efficien of .9 and power factor of .8. How much current is required?

Since the brake horse power of the motor is given, it is necessary obtain the electrical horse power, thus

$$\text{E. H. P.} = \frac{\text{brake horse power}}{\text{efficiency}} = \frac{50}{.9} = 55.5$$

which in watts is

$$55.5 \times 746 = 41{,}403$$

which is the actual load, and from which

$$\text{apparent load} = \frac{\text{actual load}}{\text{power factor}} = \frac{41{,}403}{.8} = 51{,}754$$

The current therefore at 440 volts is

$$\frac{\text{apparent load}}{\text{volts}} = \frac{51{,}754}{440} = 117.6 \text{ amperes}$$

EXAMPLE.—A 50 horse power single phase 440 volt motor, having a full load efficiency of .92 and power factor of .8, is to be operated at a distance of 1,000 feet from the alternator. The wires are to be spaced 6 inches apart and the frequency is 60, and % loss 5. Determine: **A,** *electrical horse power;* **B,** *watts;* **C,** *apparent load;* **D,** *current;* **E,** *size of wires;* **F,** *drop;* **G,** *voltage at the alternator.*

A, *Electrical horse power*

$$\text{E. H. P.} = \frac{\text{brake horse power}}{\text{efficiency}} \times \frac{50}{.92} = 54.3$$

or,

$$54.3 \times 746 = 40{,}508 \text{ watts}$$

TABLE OF WIRE EQUIVALENTS

(Brown and Sharpe gauge)

0000	2 No. 0	4 No. 3	8 No. 6	16 No. 9	32 No. 12	64 No. 15
000	2 " 1	4 " 4	8 " 7	16 " 10	32 " 13	64 " 16
00	2 " 2	4 " 5	8 " 8	16 " 11	32 " 14	64 " 17
0	2 " 3	4 " 6	8 " 9	16 " 12	32 " 15	64 " 18
1	2 " 4	4 " 7	8 " 10	16 " 13	32 " 16	64 " 19
2	2 " 5	4 " 8	8 " 11	16 " 14	32 " 17	64 " 20
3	2 " 6	4 " 9	8 " 12	16 " 15	32 " 18	64 " 21
4	2 " 7	4 " 10	8 " 13	16 " 16	32 " 19	64 " 22
5	2 " 8	4 " 11	8 " 14	16 " 17	32 " 20	64 " 23
6	2 " 9	4 " 12	8 " 15	16 " 18	32 " 21	64 " 24
7	2 " 10	4 " 13	8 " 16	16 " 19	32 " 22	64 " 25
8	2 " 11	4 " 14	8 " 17	16 " 20	32 " 23	64 " 26
9	2 " 12	4 " 15	8 " 18	16 " 21	32 " 24	64 " 27
10	2 " 13	4 " 16	8 " 19	16 " 22	32 " 25	64 " 28
11	2 " 14	4 " 17	8 " 20	16 " 23	21 " 26	64 " 29
12	2 " 15	4 " 18	8 " 21	16 " 24	32 " 27	64 " 30
13	2 " 16	4 " 19	8 " 22	16 " 25	32 " 28	....
14	2 " 17	4 " 20	8 " 23	16 " 26	32 " 29	....
15	2 " 18	4 " 21	8 " 24	16 " 27	32 " 30	....
16	2 " 19	4 " 22	8 " 25	16 " 28	....	....
17	2 " 20	4 " 23	8 " 26	16 " 29	....	....
18	2 " 21	4 " 24	8 " 27	16 " 30	....	....
19	2 " 22	4 " 25	8 " 28	....	....	....
20	2 " 23	4 " 26	8 " 29	....	....	....
21	2 " 24	4 " 27	8 " 30	....	....	....

B. *Watts*

$$\text{watts} = \text{E. H. P.} \times 746 = 54.3 \times 746 = 40{,}508$$

C. *Apparent load*

$$\text{apparent load or kva} = \frac{\text{actual load or watts}}{\text{power factor}} = \frac{40{,}508}{.8} = 50{,}635$$

D. *Current*

$$\text{current} = \frac{\text{apparent load or kva}}{\text{volts}} = \frac{50{,}635}{440} = 115 \text{ amperes}$$

E. *Size of wires*

$$\text{cir. mils} = \frac{\text{watts} \times \text{feet} \times \text{M}}{\% \text{ loss} \times \text{volts}^2} = \frac{40{,}508 \times 1{,}000 \times 3{,}380}{5 \times 440^2} = 141{,}443$$

From table page 1,907, nearest size *larger* wire is No. 00 B. & S. gauge.

F. *Drop*

$$\text{drop} = \frac{\% \text{ loss} \times \text{volts}}{100} \times \text{S} = \frac{5 \times 440}{100} \times 1.17 = 25.74 \text{ volts}$$

NOTE.—Values of S are given on page 1910.

G. *Voltage at alternator*

$$\text{alternator pressure} = \text{volts at motor} + \text{drop} = 440 + 25.74 = 465.7 \text{ volts.}$$

CHAPTER LXVI

POWER STATIONS

The term *power station* is usually applied to any building containing an installation of machinery for the conversion of energy from one form into another form. There are three general classes of station:

1. Central stations;
2. Sub-stations;
3. Isolated plants.

These may also be classified with respect to their function as

1. Generating stations;
2. Distributing stations;
3. Converting stations;

and with respect to the form of power used in generating the electric current, generating stations may be classed as

1. Steam electric;
2. Hydro-electric;
3. Gas electric, etc.

Central Stations.—It must be evident that the general type of central station to be adapted to a given case, that is to say, the general character of the machinery to be installed depen upon the kind of natural energy available for conversion into electrical energy, and the character of the electrical energy required by the consumers.

This gives rise to a further classification, as

1. Alternating current stations;
2. Direct current stations;
3. Alternating and direct current station.

The alternators or dynamos may be driven by steam or water turbines, reciprocating engines, or gas engines, according to the character of the natural energy available.

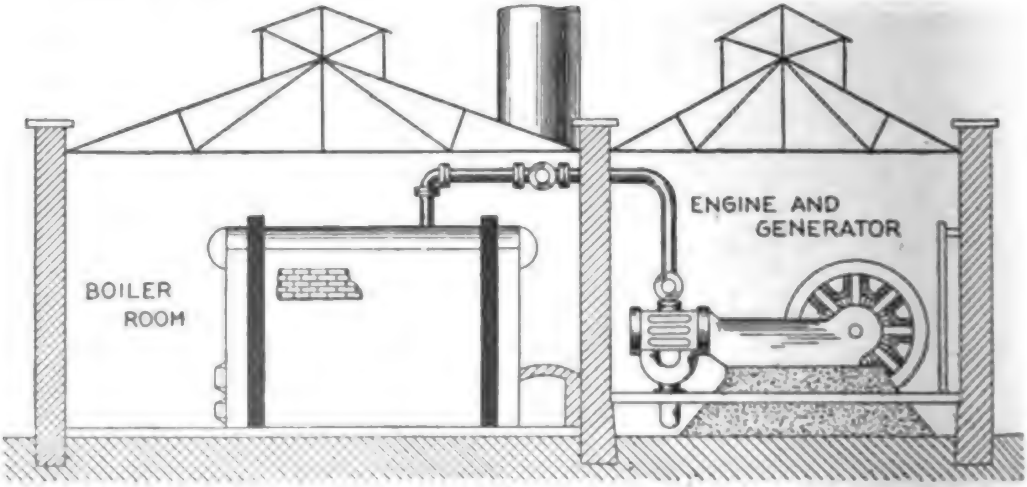


FIG. 2,705.—Elevation of small station with direct drive, showing arrangement of the boiler and engine, piping, etc.

Ques. Why is the reciprocating engine being largely replaced by the steam turbine, especially for large units?

Ans. Because of its higher rotative speed, and absence of a multiplicity of bearings which in the case of a high speed, reciprocating engine must be maintained in close adjustment for the proper operation of the engine.

The higher speed of rotation results in a more compact unit, desirable for driving high frequency alternators.

Ques. Is the steam turbine more economical than a high duty reciprocating engine?

Ans. No.

Location of Central Stations.—As a rule, central stations should be so located that the average loss of voltage in overcoming the resistance of the lines is a minimum, and this point is located at the center of gravity of the system. In fig. 2,706 is shown a graphical method of locating this important spot.

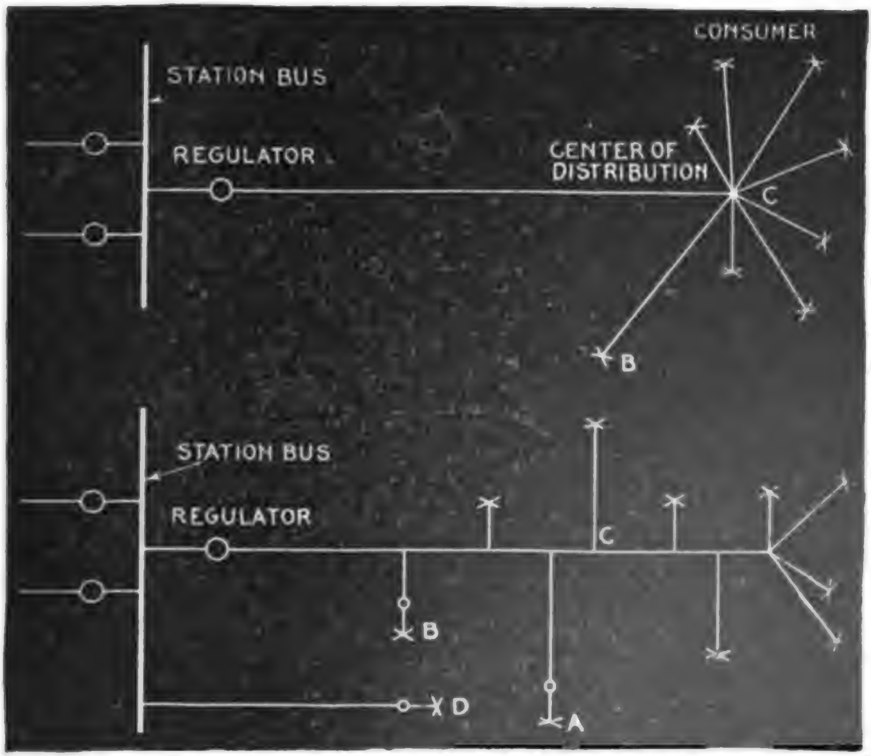


FIG. 2,706.—Diagram illustrating graphical method of determining the *center of gravity* of a system in locating the central station.

Suppose a rough canvass of prospective consumers in a district to be supplied with electric light or power shows the principal loads to be located at A, B, C, D, E, etc., and for simplicity assume that these loads will be approximately equal, so that each may be denoted by 1 for example:

The relative locations of A, B, C, D, E, etc., should be drawn to scale (say 1 inch to the 1,000 feet) after which the problem resolves itself into finding the location of the station with respect to this scale.

The solution consists in first finding the center of gravity of any two of the loads, such as those at A and B. Since each of these is 1, they will together have the same effect on the system as the resultant load of 1 and 1, or 2, located at their center of gravity, this point being so chosen that the product of the loads by their respective distances from this point will in both cases be equal.

The loads being equal in this case the distances must be equal in order that the products be the same, so that the center of gravity of A + B is at G, which point is midway between A and B.

Considering, next, the resultant load of 2 at G and the load of 1 at C, the resultant load at the center of gravity of these will be 3, and this must be situated at a distance of two units from C and one unit from G so that the distance 2 times the load 1 at C equals the distance 1 times the load 2 at G. Having thus located the load 3 at H, the same method is followed in finding the load 4 at I. Then in like manner the resultant load 4 and the load 1 at E gives a load 5 at S.

The point S being the last to be determined represents, therefore, the position of the center of gravity of the entire system, and consequently the proper position of the plant in order to give the minimum loss of voltage on the lines.

FIG. 2,707.—Exterior of central station at Lewis, Ia.; example of very small station located in the principal business section of a town. It also illustrates the use of a direct connected gasoline electric set. The central station is located on Main Street, which is the principal thoroughfare, and is installed in a low one story building for which a mere nominal rental charge is paid, the company having the option to buy the property later at the value of the land plus the cost of the improvements and simple interest on the same. To the front of an old frame building about 16 feet by 28 feet has been built a neat, well lighted concrete block room, about 16 feet by 16 feet, carrying the building to the lot line and affording ample space for the generating set and switchboards, and such desk room as is needed for the ordinary office business of the company. In this room, which is finished in natural pine with plastered walls, has been installed a standard General Electric 25 kw. gasolene electric generating set consisting of a four cylinder, four cycle, vertical water cooled, 43-51 H.P. gasoline engine, direct connected to a three phase, 2,300 volt, 600 R.P.M. alternator with a 125 volt exciter mounted on the same shaft and in the same frame. With the generating set is a slate switchboard panel equipped with three ammeters, one voltmeter, an instrument plug switch for voltage indication, one single pole carbon break switch, one automatic oil circuit breaker line switch and rheostats. Instrument transformers are mounted above and back of the board. For street lighting service a 4 kw. constant current transformer has been installed, and with it a gray marble switchboard panel mounted on iron frames and carrying an ammeter and a four point plug switch. On a board near the generator set are mounted in convenient reach suitable wrenches, spanners, and repair parts and tools. To cool the engine cylinders five 6 × 8 steel tanks have been installed in the old building, a pump on engine giving forced circulation.

Ques. Is the center of gravity of the system, as obtained in fig. 2,706, the proper location for the central station?

Ans. It is very rarely the best location.

Ques. Why?

Ans. Other conditions, such as the price of land, difficulty of obtaining water, facilities for delivery of coal and removal of ashes, etc., may more than offset the minimum line losses and copper cost due to locating the station at the center of gravity of the system.

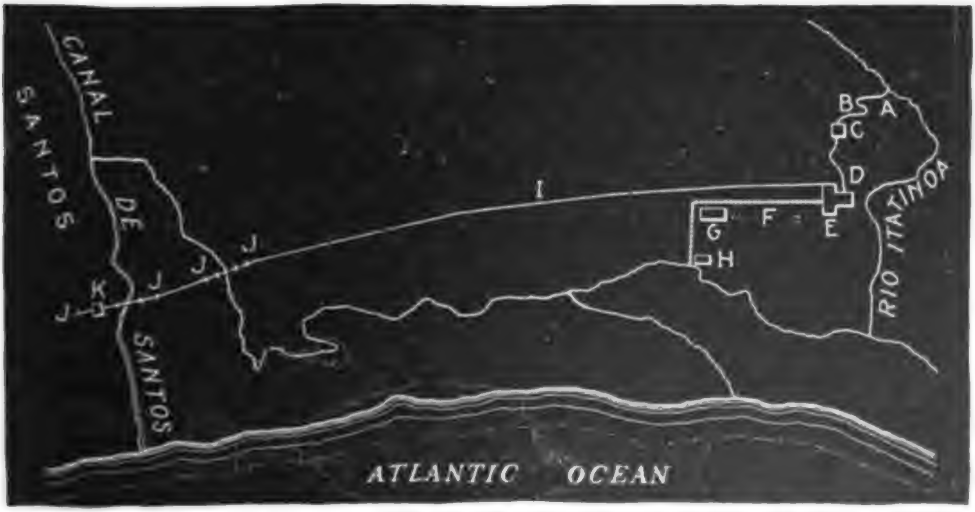


FIG. 2,708.—Map of Cia Docas de Santos hydro-electric system; an example of station location remote from the center of distribution. In the figure A is the intake; B, flume; C, forebay; D, penstocks; E, power house; F, narrow gauge railway; G, general store; H, point of debarkation; I, transmission line; J, dead ends; K, sub-station. Santos, in the republic of Brazil, is one of the great coffee shipping ports of the world, and for the development of its water front has required an elaborate system of quays. These have been developed by the Santos Dock Company, which holds a concession for the whole water front. The company, needing electric power for its own use, has developed a system deriving its power from a point about thirty miles from the city, where a small stream plunges down the sea coast from the mountain range that runs along it. The engineers have estimated that 100,000 horse power can be obtained from this source.

Ques. How then should the station be located?

Ans. The more practical experience the designer has had, and the more common sense he possesses, the better is he equipped to handle the problem, as the solution is generally such that it cannot be worked out by any rule of thumb method.

Ques. What are the general considerations with respect to the price of land?

Ans. The cost for the station site may be so high as to necessitate building or renting room at a considerable distance from the district to be supplied.

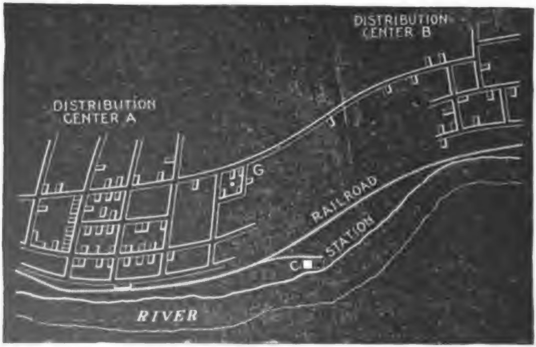


FIG. 2,709.—Station location. The figure shows two distribution centers as a town A and suburb B supplied with electricity from one station. For minimum cost of copper the location of the station would be at G, the center of gravity. However, it is very rarely that this is the best location. For instance at C, land is cheaper than at G, and there is room for future extension to the station, as shown by the dotted lines, whereas at G, only enough land is available for present requirements. Moreover C is near the railroad where coal may be obtained without the expense of cartage, and being located at the river, the plant may be run condensing thus effecting considerable economy. The conditions may sometimes be such that any one of the advantages to be secured by locating the station at C may more than offset the additional cost of copper.

If the price of land selected for the station be high, the running expenses will be similarly affected, inasmuch as more interest must then be paid on the capital invested.

The price or rent of real estate might also in certain instances alter the proposed interior arrangement of the station, particularly so in the case of a company with small capital operating in a city where high prices prevail. In general, however, it may be stated that whatever effect the price of real estate would have upon the arrangement, operation and location of a central station it can quite readily and accurately be determined in advance.

Ques. With respect to the cost of the land what should be especially considered?

Ans. Room for the future extension of the plant.

Although such additional space need not be purchased at the time of the original installation it is well, if possible, to make provision whereby it can be obtained at a reasonable figure when desired. The preliminary canvass of consumers will aid in deciding the amount of space advisable to allow for future extensions; as a rule, however, it is wise to count on the plant enlarging to not less than twice its original size, as often the dimensions have to be increased four and even six times those found sufficient at the beginning.

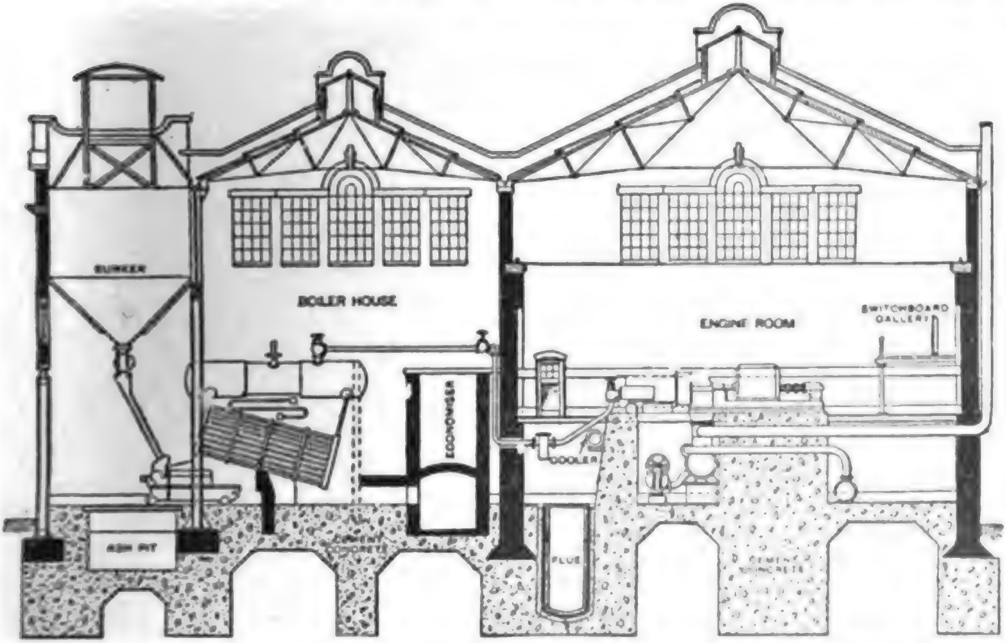


FIG. 2,710.—Section of the central station or "electricity works" at Derby, showing boiler and engine room and arrangement of bunkers, conveyor, ash pit, grates, boilers (drum, heating surface and superheater), economizer, flue, turbines, condenser pumps, etc.; also location of switchboard gallery and system of piping.

Ques. What trouble is likely to be encountered with an illy located plant after it is in operation?

Ans. It may be considered a nuisance by those residing in the vicinity, occasioning many complaints.

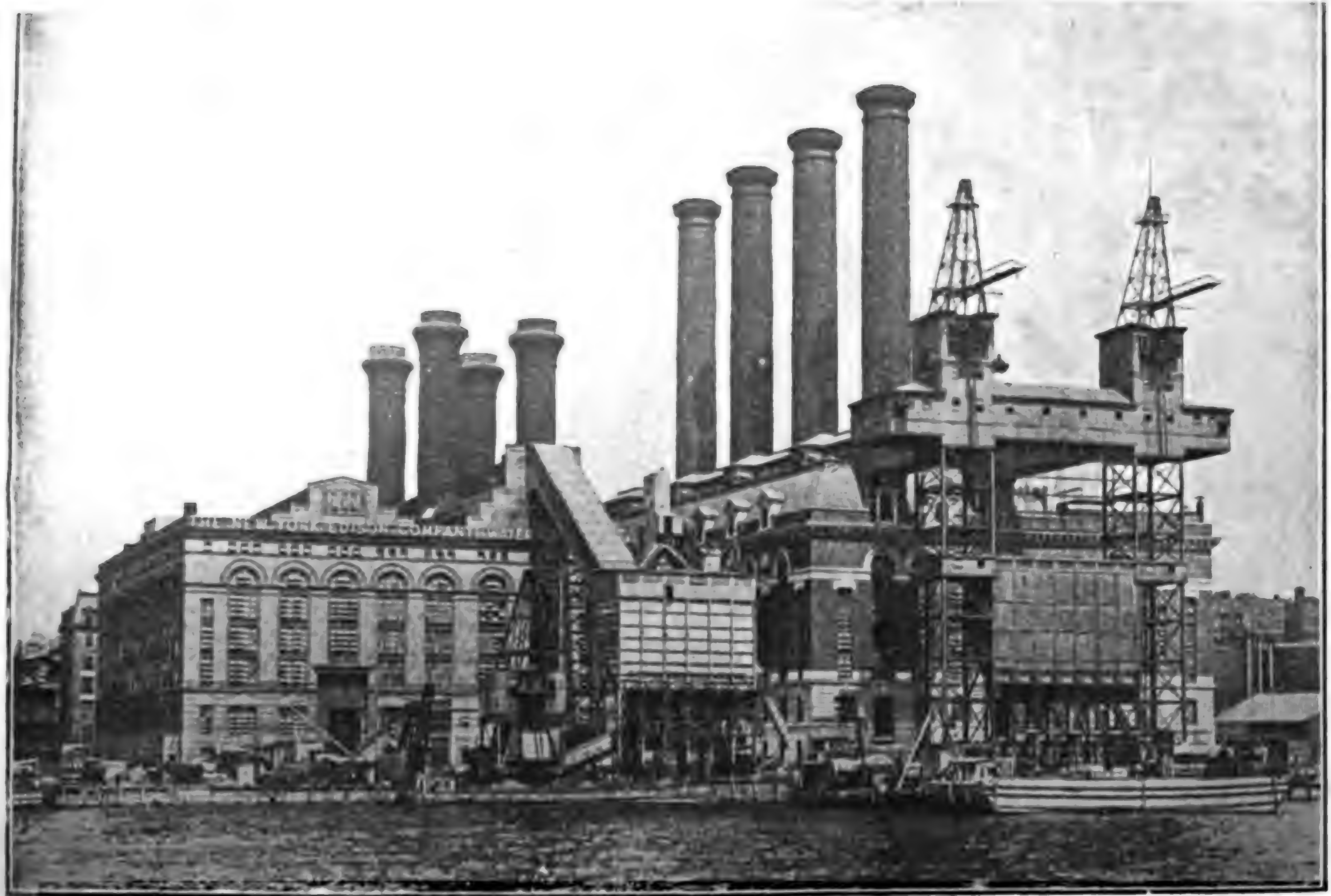


Fig. 2,711.—View of old and new Waterside stations. The new station at the right has an all turbine equipment of ten units, some Curtis and some Parsons machines, two have a capacity of 14,000 kw., and the remaining eight are of 12,000 kw. each. The old Riverside station, seen at the left is described on page 1940.

Thus, if the plant be placed in a residential section of the community the smoke, noise and vibration of the machines may become a nuisance to the surrounding inhabitants, and eventually end in suits for damage against the company responsible for the same. For these and the other reasons just given a company is sometimes forced to disregard entirely the location of a central station near the center of gravity of the system, and build at a considerable distance; such a proceeding would, if the distance be great, necessitate the installation of a high pressure system.

There might, however, be certain local laws in force restricting the use of high pressure currents on account of the danger resulting to life, that would prevent this solution of the problem. In such cases there could undoubtedly be found some site where the objections previously noted would be tolerated; thus, there would naturally be little objection to locating next to a stable, a brewery, or a factory of any description.

Ques. Why is the matter of water supply important for a central station?

Ans. Because, in a steam driven plant, water is used in the boilers for the production of steam by boiling, and if the engines be of the condensing type it is also used in them for creating a vacuum into which the exhaust steam passes so as to increase the efficiency of the engine above what it would be if the exhaust steam were obliged to discharge into the comparatively high pressure of the atmosphere.

The force of this will be apparent by considering that the water consumption of the engine ordinarily is from 15 to 25 lbs. of "feed water" per horse power per hour, and the amount of "circulating water" required to maintain the vacuum is about 25 to 30 times the feed water, and in the case of turbines with their 28 or 29 inch vacuum, much more. For instance, a 1,000 horse power plant running on 15 lbs. of feed water and 30 to 1 circulating water would require $(1,000 \times 15) \times (30 + 1) =$ 465,000 lbs. or 55,822 gals. per hour at full capacity.

Ques. Besides price what other considerations are important with respect to water?

Ans. Its quality and the possibility of a scarcity of supply.

It is quite necessary that the water used in the boilers should be as free as possible from impurities, so as to prevent the deposition within them of any scale or sediments. The quality of the water used f condensing purposes, however, is not quite so important, although the purer it is the better.

If the plant is to be located in a city, the matter of water supply need not generally be considered, because, as a rule, it can be obtained from the waterworks; there will then, of course, be a water tax to consider and this, if large, may warrant an effort being made to obtain the water in some other way. In any event, however, the possibility of a scarcity in the supply should be reduced to a minimum.

If the plant be located in the country, some natural source of water would be utilized unless the place be supplied with waterworks, which is not generally the case. It is usual, however, to find a stream, lake or pond in the vicinity, but if none such be conveniently near, an artesian or other form of well must be sunk.

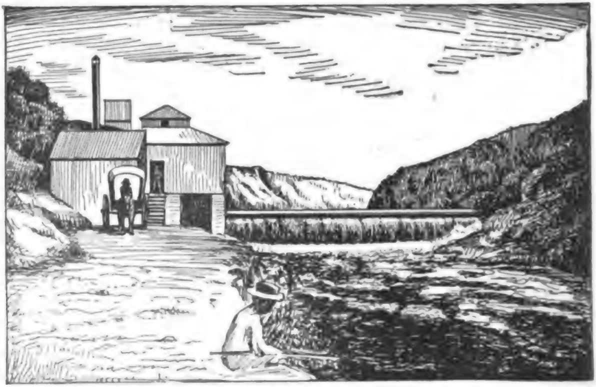


FIG. 2,712.—View illustrating the location of a station as governed by the presence of a waterfalls. In such cases the natural water power may be at a considerable distance from the center of gravity of the distribution system because of the saving in generation. In the case of long distance transmission very high pressure may be used and a transformer step down sub-station be located at or near the center of gravity of the system, thus considerably reducing the cost of copper for the transmission line.

If abundance of water exist in the vicinity of the proposed installation, not only would the location of the plant be governed thereby, but the kind of power to be used for its operation would depend thereon. Thus, if the quantity of the water were sufficient throughout the entire year to supply the necessary power, water wheels might be installed and used in place of boilers and steam engines for driving the generators. The station would then, of course, be situated close to the waterfall, regardless of the center of gravity of the system.

Ques. What should be noted with respect to the coal supply?

Ans. The facility for transporting the coal from the supply point to the boiler room.

In this connection, an admirable location, other conditions permitting, is adjacent to a railway line or water front so that coal delivered by car or boat may be unloaded directly into the bins supplying the boilers.

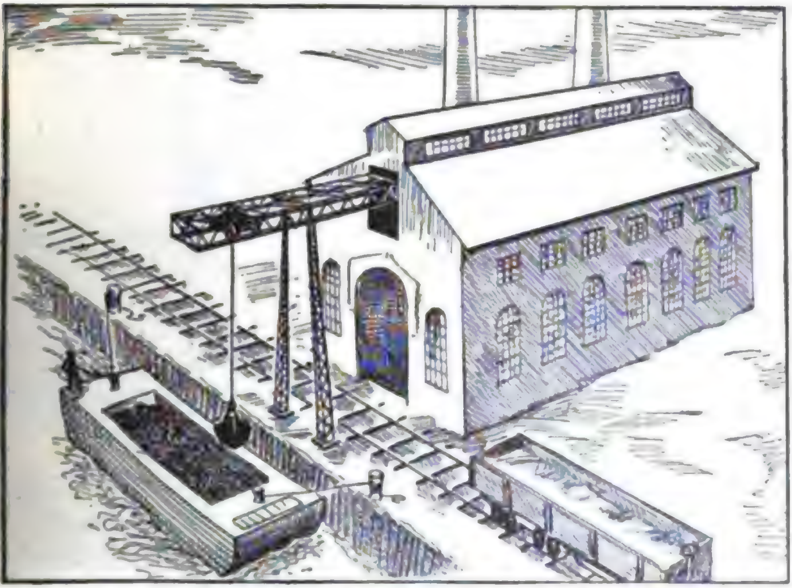


FIG. 2,713.—View of a station admirably located with respect to transportation of the coal supply. As shown, the coal may be obtained either by boat or rail, and with modern machinery for conveying the coal to the interior of the station, the transportation cost is reduced to a minimum.

If the coal be brought by train, a side or branch track will usually be found convenient, and this will usually render any carting of the fuel entirely unnecessary.

In whatever way the coal is to be supplied, the liability of a shortage due to traffic or navigation being closed at any time of the year should be well looked into, as should also the facility for the removal of ashes, before deciding upon the final location for the plant.

Choice of System.—The chief considerations in the design of a central station are economy and capacity. When the

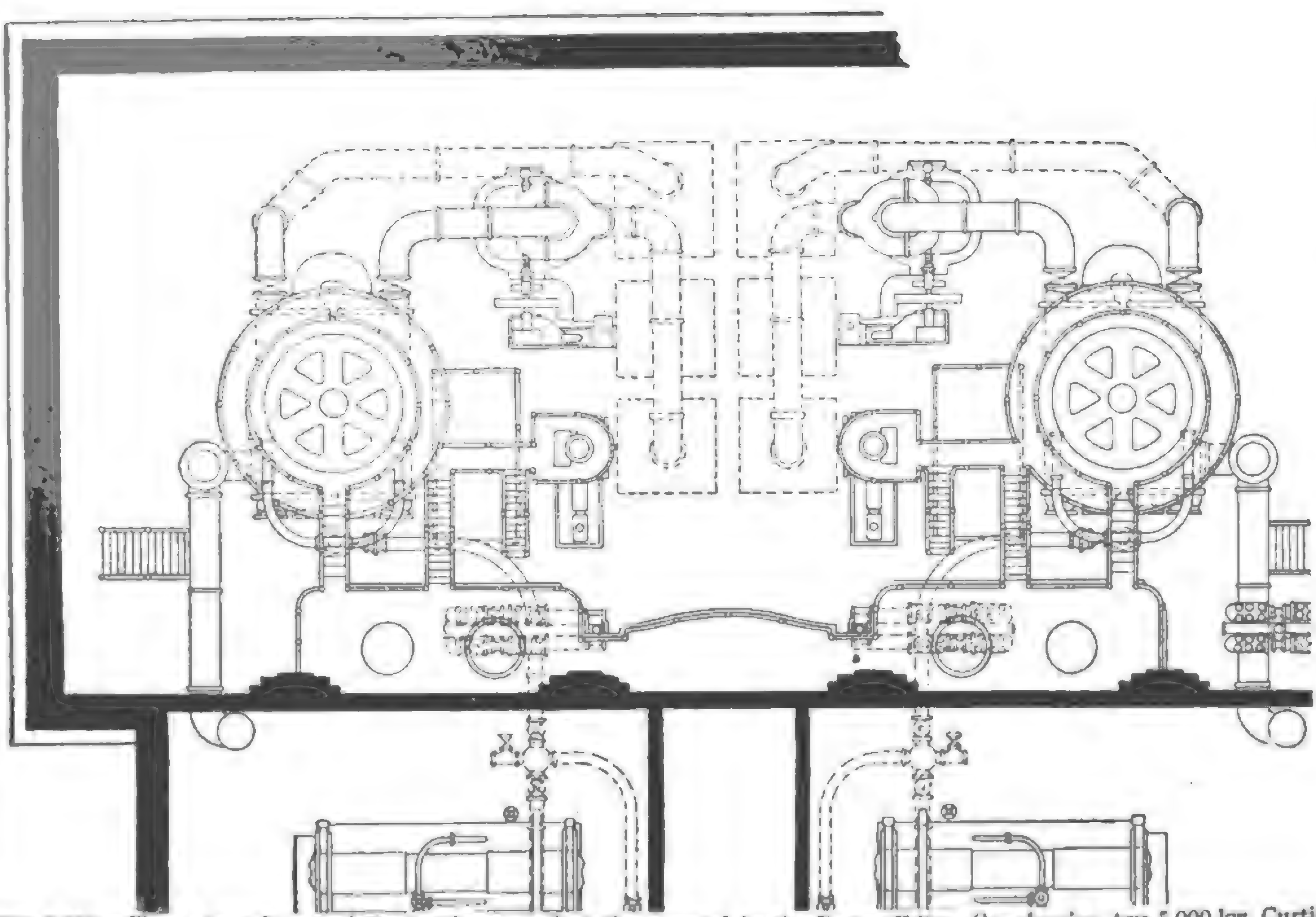


FIG. 2,714.—Floor plan of part of the turbine central station erected by the Boston Edison Co., showing two 5,000 kw. Curtis steam turbines in place. The complete installation contains twelve 5,000 kw. Curtis steam turbines, a sectional elevation being shown in fig. 2,708, page 1,921.

current has to be transmitted long distances for either lighting or power purposes, economy is attainable only by reducing the weight of the copper conductors. This can be accomplished only by the use of the high voltage currents obtainable from alternators.

Again, where the consumers are located within a radius of two miles from the central station, thereby requiring a transmission voltage of 550 volts or less, dynamos may be employed with greater economy.

Alternating current possesses serious disadvantages for certain important applications.

For instance, in operating electric railways and for lighting it is often necessary to transmit direct current at 500 volts a distance of five or ten miles. In such cases, the excessive drop cannot be economically reduced by increasing the sizes of the line wire, while a sufficient increase of the voltage would cause serious variations under changes of load. Hence, it is common practice to employ some form of auxiliary generator or booster, which when connected in series with the feeder, automatically maintains the required pressure in the most remote districts so long as the main generators continue to furnish the normal or working voltage.

The advantage of a direct current installation in such cases over a similar plant supplying alternating current line is the act that a storage battery may be used in connection with the ormer for taking up the fluctuations of the current, thereby permitting the dynamo to run with a less variable load, and onsequently at higher efficiency.

Ques. Name some services requiring direct current.

Ans. Direct current is required for certain kinds of electrolytic work, such as electroplating, the electrical separation of metals, tc., also the charging of storage batteries for electric automobiles

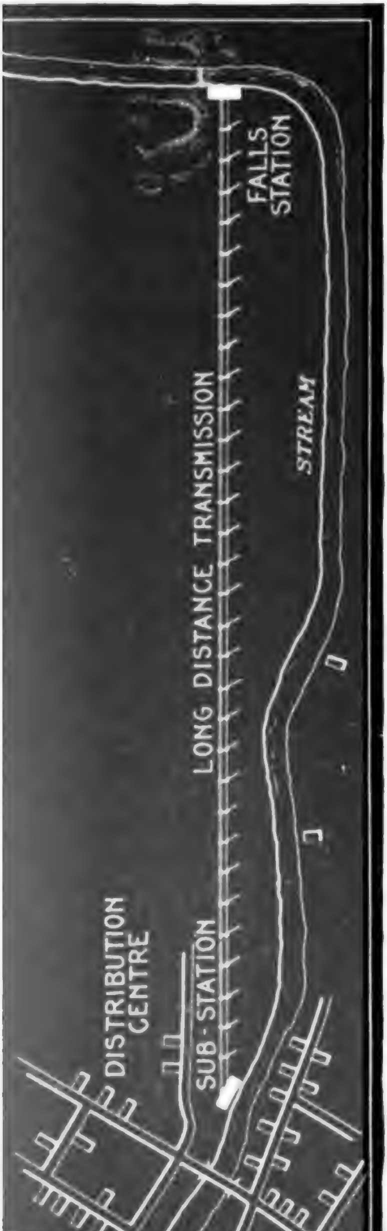


FIG. 2,715.—Example of central station located remote from the distributing center and furnishing alternating current at high pressure to a sub-station where the current is passed through step down transformers and supplied at moderate pressure to the distribution system. In some cases the sub-station contains also converters supplying direct current for battery charging, electro-plating, etc.

Ques. How is direct current supplied?

Ans. Sometimes the centra station is equipped with suitabl apparatus for supplying both direct and alternating current This may be accomplished i several different ways: By installing both direct and alternating current generators in the central station; by the use o double current generators o dynamotors, from which direct current may be taken from one side and alternating current from the other side; or by installing, in the sub-station of a alternating current central station, in addition to the transformers usually placed therein a rotary converter for changing or converting alternating current into direct current.

Thus, it is evident that the character of a central station will b governed to a great extent by th class of services to be supplied.

An exception to this is wher the entire output has to be transmitted a long distance to the point of utilization.

In such cases a copper economy demands the use of high tension alternating current, and its distribution to consumers may be made directly by means of step down transformers mounted near by or within the consumers' premises, or it may be transformed into low voltage alternating current by a conveniently located sub-station.

Where the current is to be used chiefly for lighting and there are only a few or no motors to be supplied, the choice between direct current and alternating current will depend greatly upon the size of the installation, direct current being preferable for small installations and alternating current for large installations.

If the current is to be used primarily for operating machinery, such as elevators, travelling cranes, machine tools and other devices of a similar character, which have to be operated intermittently and at varying speeds and loads, direct current is the more suitable; but if the motors performing such work can be operated continuously for many hours at a time under practically constant loads, as, for instance in the general work of a pumping station, alternating current may be employed with advantage.

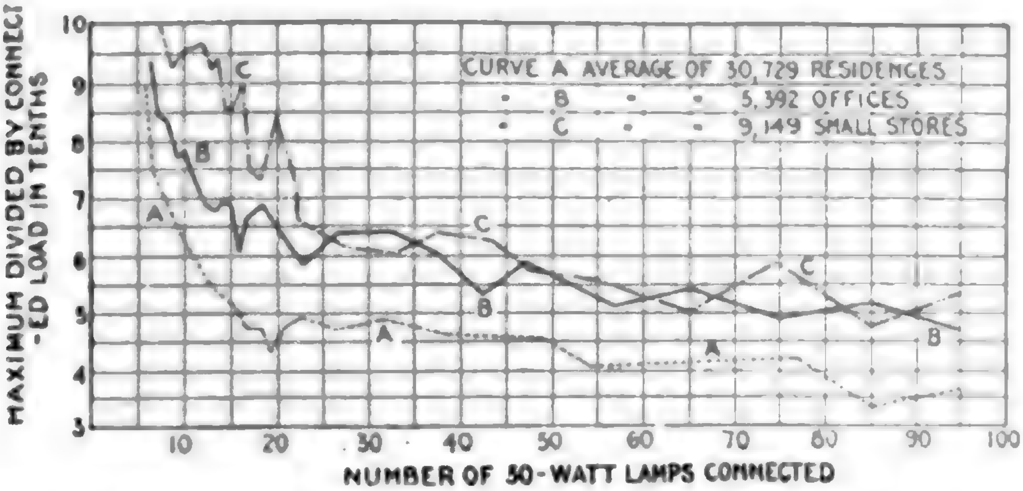


FIG. 2,716.—Diagram illustrating diversity factor. By definition *diversity factor = combined actual maximum demand of a group of customers divided by the sum of their individual maximum demands.* Example, a customer has fifty (50) watt lamps and, of course, the sum of the individual maximum demands of the lamps is 2.5 kw. watts ("connected load"). The customer's maximum demand, however, is 1.5 kw. Hence, the diversity factor* of the customer's group of lamps is $1.5 \div 2.5 = .6$. In the diagram the ordinates of the curves show the ratio *maximum demand* to *connected load* for various kinds of electric lighting service in Chicago.

Size of Plant.—Before any definite calculation can be made, or plans drawn, the engineer must determine the probable load. This is usually ascertained in terms of the number and distances

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*NOTE.—The diversity factor of a customer's group of lamps, namely, the ratio of maximum demand to connected load is usually called the *demand factor* of the customer.

of lamps that will be required, by making a thorough canvass of the city or town, or that portion for which electrical energy is to be supplied. The probable load that the station is to carry when it begins operation, the nature of this load, and the probable rate of increase are matters upon which the design and construction chiefly depend.

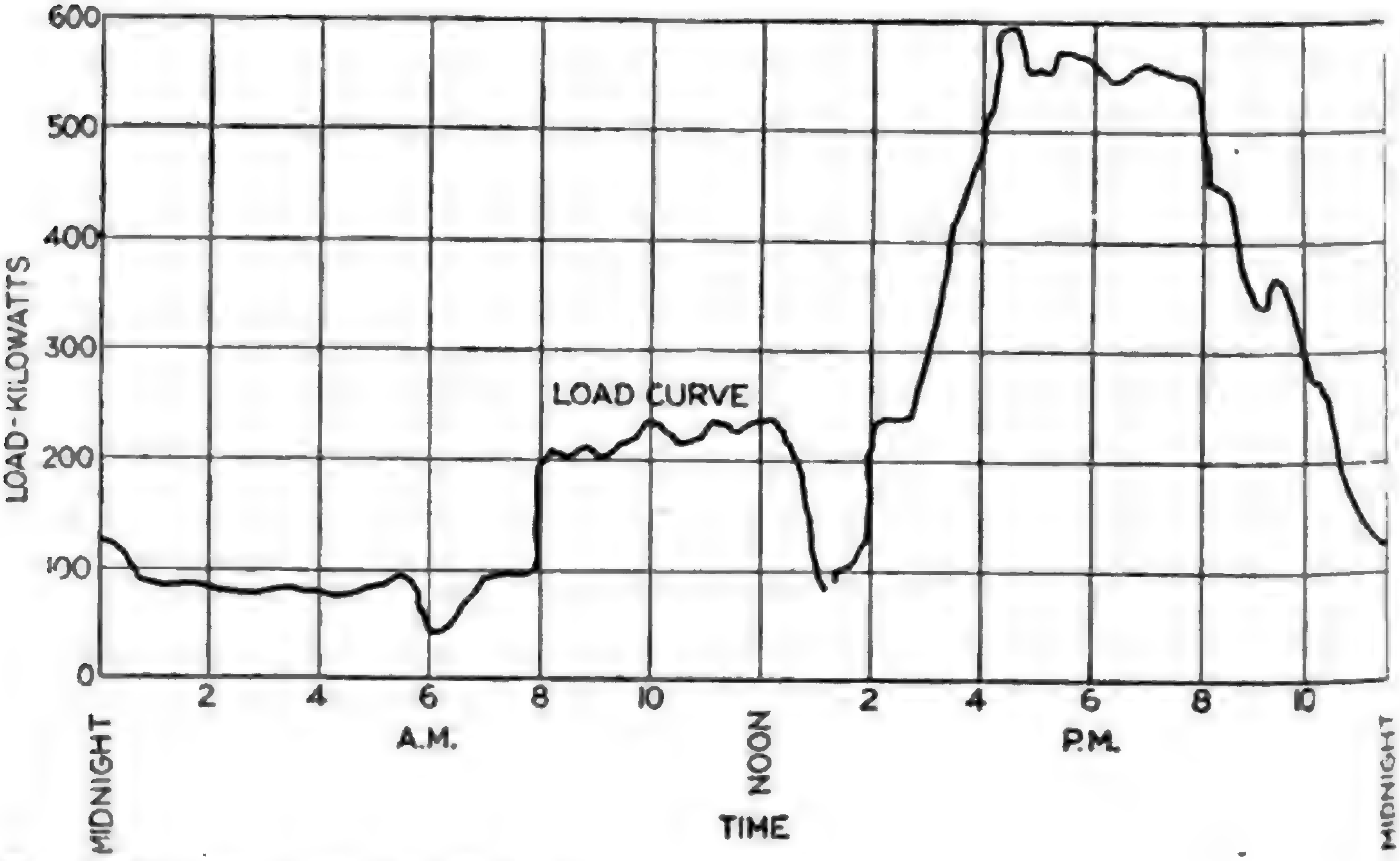


FIG. 2,717.—Load curve for one day.

Ques. What is the nature of the load carried by a central station?

Ans. It fluctuates with the time of day and also with the time of year.

Ques. How is a fluctuating load best represented?

Ans. Graphically, that is to say by means of a curve plotted on coordinate paper of which ordinates represent load values and the corresponding abscissæ time values, as in the accompanying curves.

Ques. What is the nature of a power load?

Ans. Where electricity is supplied for power purposes to a number of factories, the load is fairly steady, dropping, of course, during meal hours. In the case of traction, the average value of the load is fairly steady but there are momentarily violent fluctuations due to starting cars or trains.

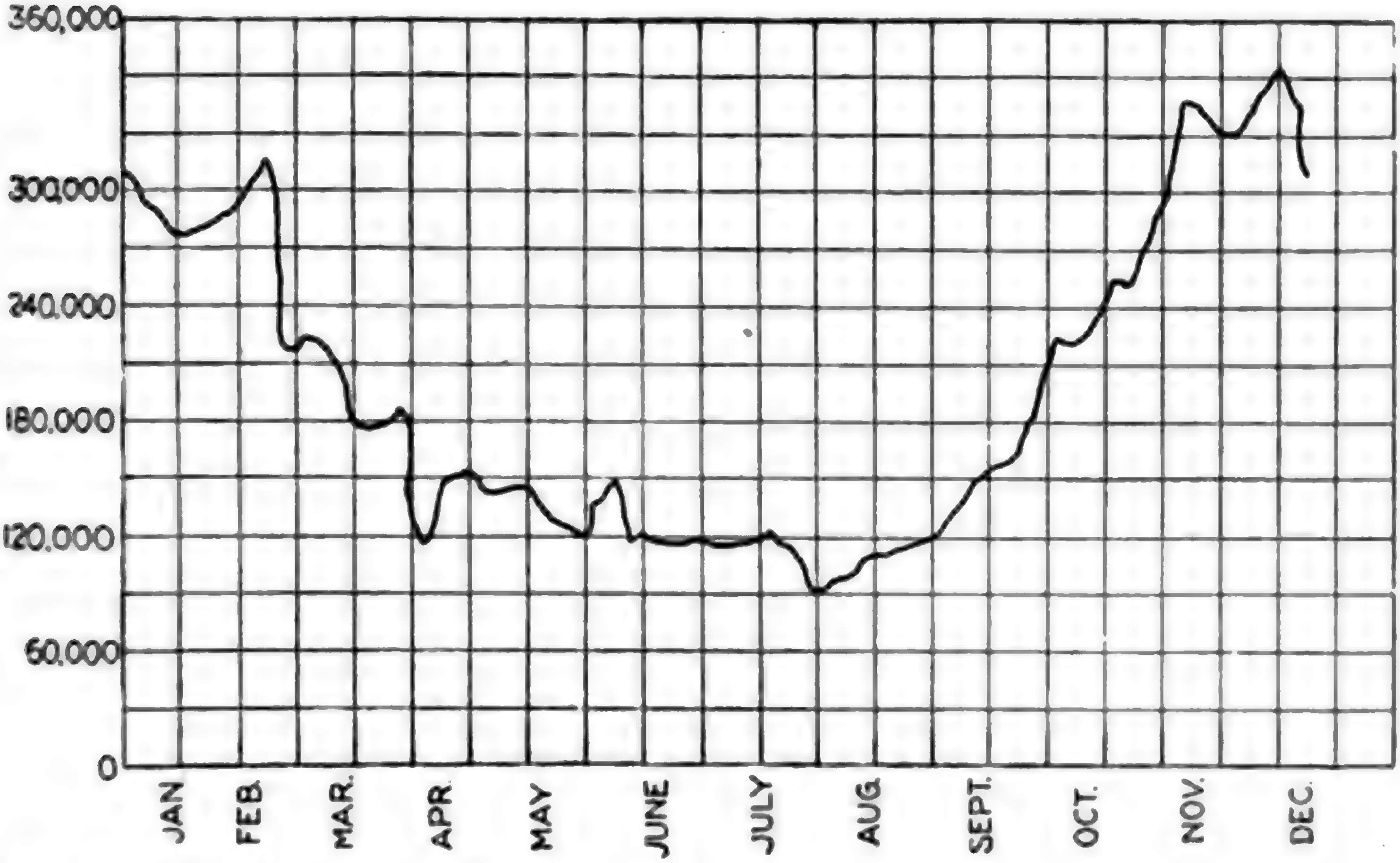


FIG. 2,718.—Load curve for one year.

Ques. What is the peak load?

Ans. The maximum load which has to be carried by the station at any time of day or night as shown by the highest point of the load curve.

Ques. Define the load factor.

Ans. The machinery of the station evidently must be large enough to carry the peak load, and therefore considerably in excess of that required for the average demand. The ratio of the average to the maximum load is called the load factor.

There are two kinds of load factor: the annual, and the daily.

The annual load factor is obtained as a percentage by multiplying the number of units sold (per year) by 100, and dividing by the product of the maximum load and the number of hours in the year. The daily load factor is obtained by taking the figures for 24 hours instead of a year.

Ques. What must be provided in addition to the machinery required to supply the peak load?

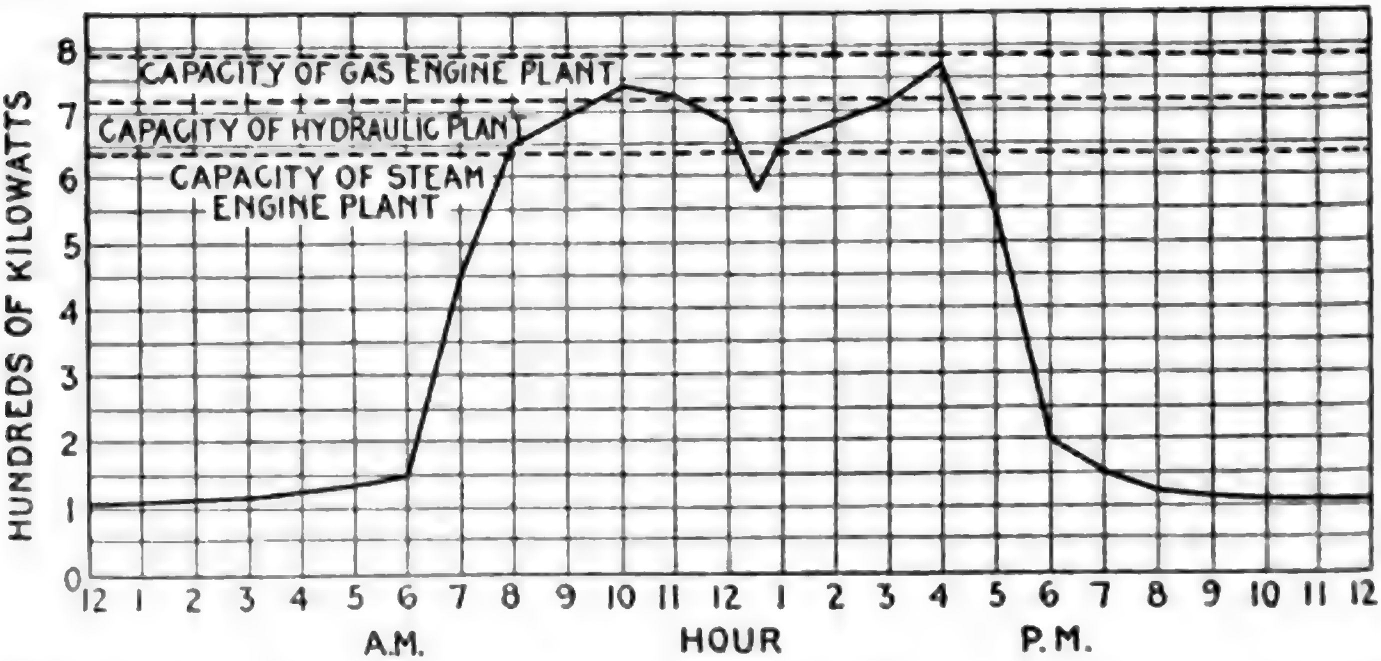


FIG. 2,719.—Load curve of plant supplying power for the operation of motors in a manufacturing district. The horizontal dotted lines show suitable power ratings. A properly designed steam plant has a large overload capacity, a hydraulic plant has a small overload capacity, and a gasoline engine plant has no overload capacity. Accordingly, the peak of the load (maximum load) may be 25 or 30 per cent. in excess of the rated capacity of a steam plant, not more than 5 or 10 per cent. in excess of the rated capacity of a hydraulic plant, not at all in excess of the rated capacity of a gas engine plant.

Ans. Additional units must be installed for use in case of repairs or break down of some of the other units.

EXAMPLE.—What would be the boiler horse power required to generate 5,000 kw. under the following conditions: Efficiency of generators 85%; efficiency of engines 90%; feed water of engines and auxiliaries 15 lbs. per I. H. P.; boiler pressure 175 lbs.; temperature of feed water 150° Fahr? With a rate of combustion of 15 lbs. of coal per sq. foot of grate per hour and an evaporation (from and at 212°) of 8 lbs. of water per lb. of coal, what area of grate would be required and how much heating surface?

5,000 kw. = 5,000 ÷ .746 = 6,702 electrical horse power

To obtain this electrical horse power with alternators whose efficiency is 85% requires

$$6{,}702 \div .85 = 7{,}885 \text{ brake horse power at the engine}$$

This, with mechanical efficiency of 90% is equivalent to

$$7{,}885 \div .9 = 8{,}761 \text{ indicated horse power}$$

Since 15 lbs. of feed water are required for the engines and auxiliaries per indicated horse power per hour, the total feed water or evaporation required to generate 5,000 kw. is

$$15 \times 8{,}761 = 131{,}415 \text{ lbs. per hour.}$$

that is to say, the boilers must be of sufficient capacity to generate 131,415 lbs. of steam per hour from water at a temperature of 150° Fahr. This must be multiplied by the *factor of evaporation* for steam at 175 lbs pressure from feed water at a temperature of 150°, in order to get the equivalent evaporation "*from and at 212°.*"

The formula for the factor of evaporation is

$$\text{factor of evaporation} = \frac{H - h}{965.7} \quad . \quad . \quad . \quad . \quad (1)$$

in which

H = total heat of steam at the observed pressure;

h = total heat of feed water of the observed temperature;

965.7 = latent heat, of steam at atmospheric pressure.

Substituting in (1) values for the observed pressure and temperature as obtained from the steam table

$$\text{factor of evaporation} = \frac{1{,}197 - 118}{965.7} = 1.117$$

for which the equivalent evaporation "*from and at 212°*" is

$$131{,}415 \times 1.117 = 146{,}791 \text{ lbs. per hour}$$

FACTORS OF EVAPORATION

Temp. of feed water. Deg. Fahr.	Steam Pressure by Gauge												
	50	60	70	80	90	100	110	120	130	140	150	160	170
32	1.214	1.216	1.220	1.222	1.225	1.227	1.229	1.231	1.232	1.234	1.236	1.237	1.239
40	1.206	1.209	1.212	1.214	1.216	1.219	1.220	1.222	1.224	1.226	1.227	1.229	1.230
50	1.195	1.197	1.201	1.204	1.206	1.208	1.210	1.212	1.214	1.215	1.217	1.218	1.220
60	1.185	1.188	1.191	1.193	1.196	1.198	1.200	1.202	1.203	1.205	1.207	1.208	1.210
70	1.175	1.178	1.180	1.183	1.185	1.187	1.189	1.191	1.193	1.194	1.196	1.197	1.199
80	1.164	1.167	1.170	1.173	1.175	1.177	1.179	1.181	1.183	1.184	1.186	1.187	1.189
90	1.154	1.157	1.160	1.162	1.165	1.167	1.169	1.170	1.172	1.174	1.176	1.177	1.179
100	1.144	1.147	1.150	1.152	1.154	1.156	1.158	1.160	1.162	1.164	1.165	1.167	1.168
110	1.133	1.136	1.139	1.142	1.144	1.146	1.148	1.150	1.152	1.153	1.155	1.156	1.158
120	1.123	1.126	1.129	1.131	1.133	1.136	1.138	1.140	1.141	1.143	1.145	1.146	1.147
130	1.113	1.116	1.118	1.121	1.123	1.125	1.127	1.129	1.130	1.132	1.134	1.136	1.137
140	1.102	1.105	1.108	1.110	1.113	1.115	1.117	1.119	1.120	1.122	1.124	1.125	1.127
150	1.091	1.095	1.098	1.100	1.102	1.104	1.106	1.108	1.110	1.111	1.113	1.115	1.116
160	1.081	1.084	1.087	1.090	1.092	1.094	1.096	1.098	1.100	1.101	1.103	1.104	1.106
170	1.070	1.074	1.077	1.079	1.081	1.083	1.085	1.087	1.089	1.091	1.092	1.094	1.095
180	1.060	1.063	1.066	1.069	1.071	1.073	1.075	1.077	1.079	1.080	1.082	1.083	1.085
190	1.050	1.053	1.056	1.058	1.060	1.063	1.065	1.066	1.068	1.070	1.071	1.073	1.074
200	1.039	1.043	1.045	1.048	1.050	1.052	1.054	1.056	1.058	1.059	1.061	1.063	1.064
210	1.029	1.032	1.035	1.037	1.040	1.042	1.044	1.046	1.047	1.049	1.051	1.052	1.053

Temp. of feed water. Deg. Fahr.	Steam Pressure by Gauge												
	180	190	200	210	220	230	240	250	260	270	280	290	300
32	1.240	1.241	1.243	1.244	1.245	1.246	1.247	1.248	1.250	1.251	1.252	1.253	1.254
40	1.232	1.233	1.234	1.236	1.237	1.238	1.239	1.240	1.241	1.242	1.243	1.244	1.245
50	1.221	1.223	1.224	1.225	1.226	1.228	1.229	1.230	1.231	1.232	1.233	1.234	1.235
60	1.211	1.212	1.214	1.215	1.216	1.217	1.218	1.219	1.220	1.221	1.222	1.223	1.224
70	1.200	1.202	1.203	1.205	1.206	1.207	1.208	1.209	1.210	1.211	1.212	1.213	1.214
80	1.190	1.192	1.193	1.194	1.195	1.196	1.198	1.199	1.200	1.201	1.202	1.203	1.204
90	1.180	1.181	1.183	1.184	1.185	1.186	1.187	1.188	1.189	1.190	1.191	1.192	1.193
100	1.170	1.171	1.172	1.174	1.175	1.176	1.177	1.178	1.179	1.180	1.181	1.182	1.183
110	1.159	1.160	1.162	1.163	1.164	1.166	1.167	1.168	1.169	1.170	1.171	1.172	1.173
120	1.149	1.150	1.151	1.153	1.154	1.155	1.156	1.157	1.158	1.159	1.160	1.161	1.162
130	1.138	1.140	1.141	1.142	1.144	1.145	1.146	1.147	1.148	1.149	1.150	1.151	1.152
140	1.128	1.129	1.131	1.132	1.133	1.134	1.135	1.136	1.137	1.138	1.139	1.140	1.141
150	1.118	1.119	1.120	1.121	1.123	1.124	1.125	1.126	1.127	1.128	1.129	1.130	1.131
160	1.107	1.108	1.110	1.111	1.112	1.113	1.115	1.116	1.117	1.118	1.119	1.120	1.121
170	1.097	1.098	1.099	1.101	1.102	1.103	1.104	1.105	1.106	1.107	1.108	1.109	1.110
180	1.086	1.088	1.089	1.090	1.091	1.093	1.094	1.095	1.096	1.097	1.098	1.099	1.100
190	1.076	1.077	1.078	1.080	1.081	1.082	1.083	1.084	1.085	1.086	1.087	1.088	1.089
200	1.065	1.067	1.068	1.069	1.071	1.072	1.073	1.074	1.075	1.076	1.077	1.078	1.079
210	1.055	1.056	1.057	1.059	1.066	1.061	1.062	1.063	1.064	1.065	1.066	1.067	1.068

One boiler horse power being equal to *an evaporation of 34½ lbs. of water from a feed water temperature of 212° Fahr., into steam at the same temperature*, the boiler capacity is accordingly

148,105 ÷ 34½ = 4,293 boiler horse power.

The rate of evaporation is given at 8 lbs. of water (from and at 212° Fahr.), for which the fuel required is

148,105 ÷ 8 = 18,513 lbs. of coal per hour.

For a rate of combustion of 15 lbs. of coal per hour per square foot of grate,

grate area = 18,513 ÷ 15 = 1,234 sq. ft.

For stationary boilers the usual ratio of heating surface to grate area is 35:1, accordingly the heating surface corresponding to this ratio is

1,234 × 35 = 43,190 sq. ft.

The above calculation is based on a rate of evaporation of 8 lbs. of water per lb. of coal and a rate of combustion of 15 lbs. of coal per sq. ft. of grate. For other rates the required grate area may be obtained from the following table:

GRATE SURFACE PER HORSE POWER (KENT)

	Pounds of water from and at 212° per pound of coal	Pounds of coal per h.p. per hour	Pounds of coal burned per square foot of grate per hour								
			8	10	12	15	20	25	30	35	40
			Square feet grate per horse power								
Good coal and boiler	10	3.45	.43	.35	.29	.23	.17	.14	.11	.10	.09
	9	3.83	.48	.38	.32	.25	.19	.15	.13	.11	.10
Fair coal or boiler	8.61	4.	.50	.40	.33	.26	.20	.16	.13	.12	.10
	8	4.31	.54	.43	.36	.29	.22	.17	.14	.13	.11
	7	4.93	.62	.49	.41	.33	.24	.20	.17	.14	.12
Poor coal or boiler	6.9	5.	.63	.50	.42	.34	.25	.20	.17	.15	.13
	6	5.75	.72	.58	.48	.38	.29	.23	.19	.17	.14
	5	6.9	.86	.69	.58	.46	.35	.28	.23	.22	.17
Lignite and poor boiler	3.45	10.	1.25	1.00	.83	.67	.50	.40	.33	.29	.25

General Arrangement of Station.—In designing an electrical station, it is preferable that whatever rooms or divisions of the interior space are desired should determine the total outside dimensions of the plant in the original plans of the building than that these latter dimensions be fixed and the rooms, etc., be fitted in afterward.

SAVING DUE TO HEATING THE FEED WATER

Table showing the percentage of saving for each degree of increase in temperature of feed water heated by waste steam.

Initial temp. of feed	PRESSURE OF STEAM IN BOILER, LBS. PER SQ. INCH ABOVE ATMOSPHERE											Initial temp. of feed
	0	20	40	60	80	100	120	140	160	180	200	
32°	.0872	.0861	.0855	.0851	.0847	.0844	.0841	.0839	.0837	.0835	.0833	32
40	.0878	.0867	.0861	.0856	.0853	.0850	.0847	.0845	.0843	.0841	.0839	40
50	.0886	.0875	.0868	.0864	.0860	.0857	.0854	.0852	.0850	.0848	.0846	50
60	.0894	.0883	.0876	.0872	.0867	.0864	.0862	.0859	.0856	.0855	.0853	60
70	.0902	.0890	.0884	.0879	.0875	.0872	.0869	.0867	.0864	.0862	.0860	70
80	.0910	.0898	.0891	.0887	.0883	.0879	.0877	.0874	.0872	.0870	.0868	80
90	.0919	.0907	.0900	.0895	.0888	.0887	.0884	.0883	.0879	.0877	.0875	90
100	.0927	.0915	.0908	.0903	.0899	.0895	.0892	.0890	.0887	.0885	.0883	100
110	.0936	.0923	.0916	.0911	.0907	.0903	.0900	.0898	.0895	.0893	.0891	110
120	.0945	.0932	.0925	.0919	.0915	.0911	.0908	.0906	.0903	.0901	.0899	120
130	.0954	.0941	.0954	.0928	.0924	.0920	.0917	.0914	.0912	.0909	.0907	130
140	.0963	.0950	.0943	.0937	.0932	.0929	.0925	.0923	.0920	.0918	.0916	140
150	.0973	.0959	.0951	.0946	.0941	.0937	.0934	.0931	.0929	.0926	.0924	150
160	.0982	.0968	.0961	.0955	.0950	.0946	.0943	.0940	.0937	.0935	.0933	160
170	.0992	.0978	.0970	.0964	.0959	.0955	.0952	.0949	.0946	.0944	.0941	170
180	.1002	.0988	.0981	.0973	.0969	.0965	.0961	.0958	.0955	.0953	.0951	180
190	.1012	.0998	.0989	.0983	.0978	.0974	.0971	.0968	.0964	.0962	.0960	190
200	.1022	.1008	.0900	.0993	.0988	.0984	.0980	.0977	.0974	.0972	.0969	200
210	.1033	.1018	.1000	.1003	.0998	.0994	.0990	.0987	.0984	.0981	.0979	210
220	.....	.1029	.1019	.1013	.1008	.1004	.1000	.0997	.0994	.0991	.0989	220
230	.....	.1039	.1031	.1024	.1018	.0112	.1010	.1007	.1003	.1001	.0999	230
240	.....	.1050	.1041	.1034	.1029	.1024	.1020	.1017	.1014	.1011	.1009	240
250	.....	.1062	.1052	.1045	.1040	.1035	.1031	.1027	.1025	.1022	.1019	250

NOTE.—An approximate rule for the conditions of ordinary practice is a saving of 1 per cent. made by each increase of 11° in the temperature of the feed water. This corresponds to .0909 per cent. per degree. The calculation of saving is made as follows: Boiler pressure, 100 lbs. gauge; total heat in steam above 32° = 1,185 B.T.U. feed water, original temperature 60°, final temperature 209°F. Increase in heat units, 150. Heat units above 32° in feed water of original temperature = 28. Heat units in steam above that in cold feed water, 1,185 − 28 = 1,157. Saving by the feed water heater = 150 ÷ 1,157 = 12.96 per cent. The same result is obtained by the use of the table. Increase in temperature 150° × tabular figure .0864 = 12.9 per cent. Let total heat of 1 lb. of steam at the boiler pressure = H; total heat of 1 lb. of feed water before entering the heater = h', and after passing through the heater = h''; then the saving made by the heater is $\frac{h'' - h'}{H - h'}$

Under usual conditions the plans of an electrical station are readily drawn, as they are generally of a simple nature. The engines and generators will occupy the majority of the space, and these are usually placed in one large room; in some stations, however, they are located respectively in two adjacent rooms. The boilers are generally located in a room apart from the engines and dynamos, and in some cases a separate building is provided for them; the pumps, etc., must be installed not far from the boilers, and space must also be allowed near the boilers for coal and ashes.

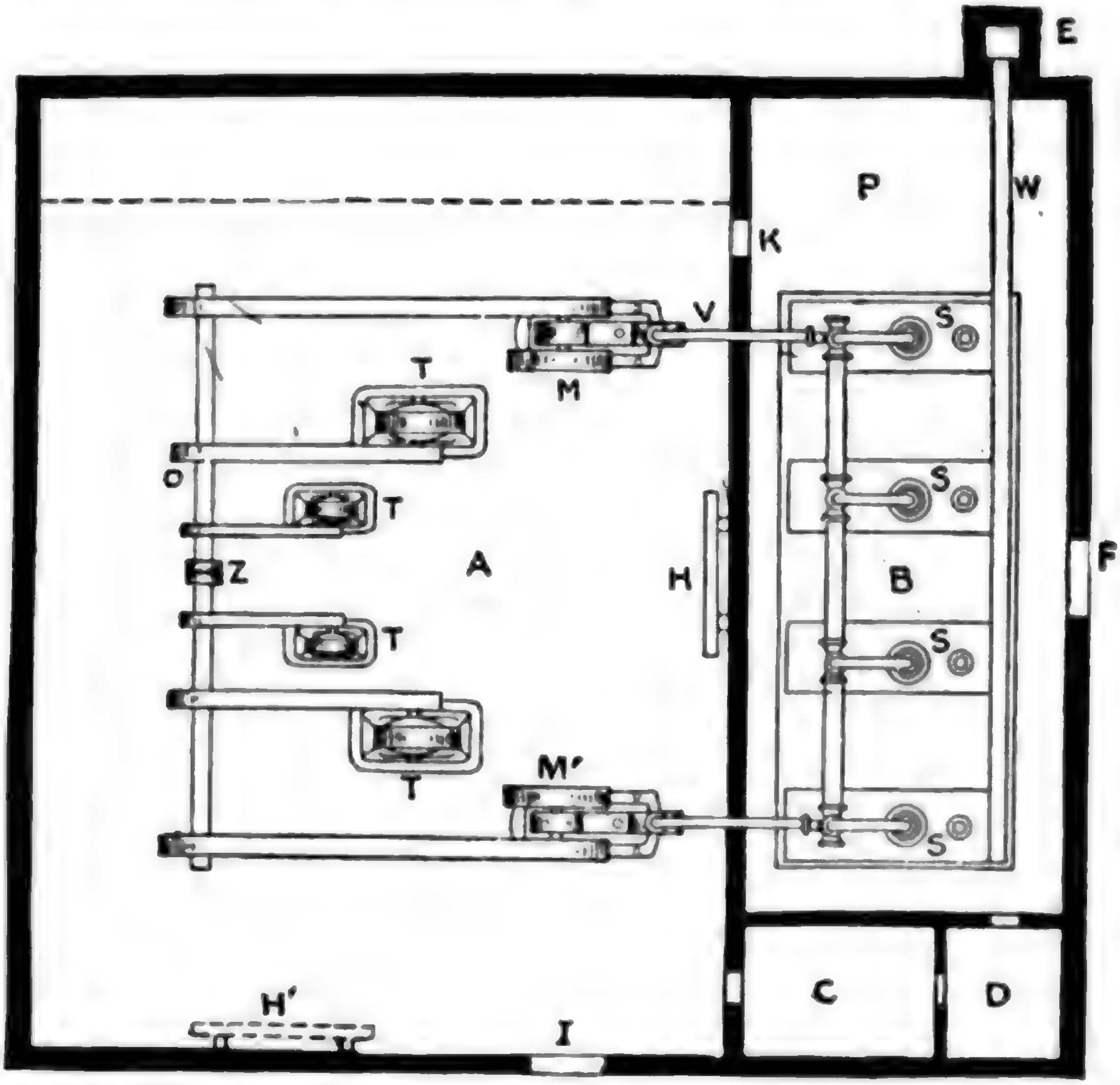


FIG. 2,720.—Floor plan of an electrical station having a belted drive with counter shaft.

Fig. 2,720 shows the floor plan of an electrical station, in which a countershaft and belted connections are used between the engine* generators. Referring first to the plan of the building itself, A represents the engine and dynamo room, B denotes the boiler room, C the office, D the store room, and E the chimney connected with the boilers by means of the uptake *w*. Referring next to the apparatus installed, S, S, S, S represents a battery of four boilers; these are connected by steam piping VV to the two steam engines, M and M, which are belted to the countershaft O. Belted to the countershaft are the generators, T, T, T, T, the circuits from which are controlled on the switchboard, H.

Ques. What are the objections to the arrangement shown in fig. 2,720.

Ans. The large space required by the belt drive especially in location where land is expensive. Another objection is the frictional loss due to the belt drive with its countershaft, etc.

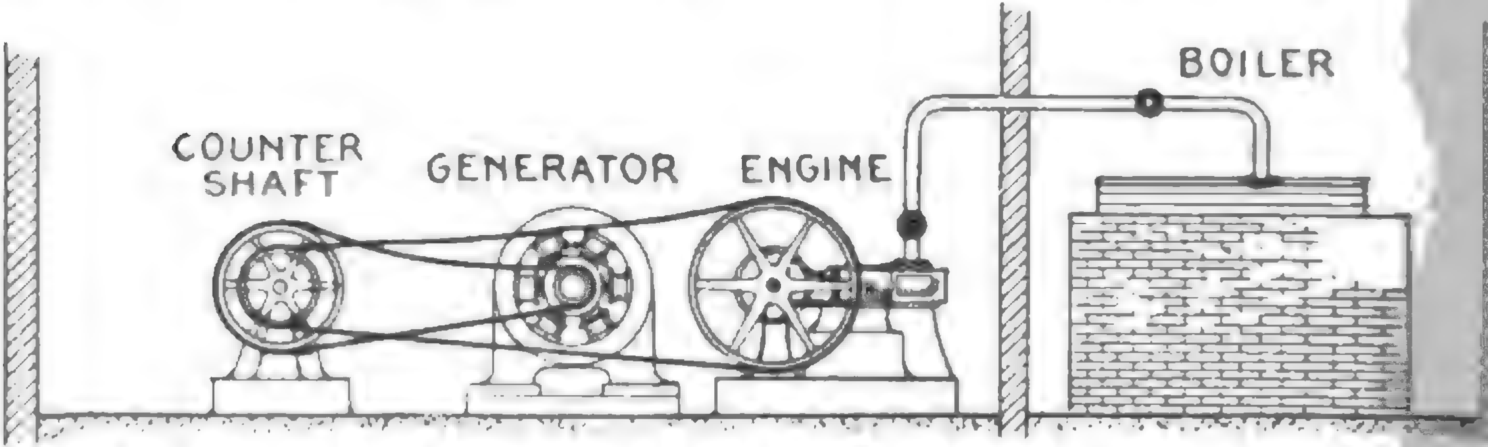


FIG. 2,721.—Elevation of station having a belted drive with countershaft, as shown in plan in fig. 2,720.

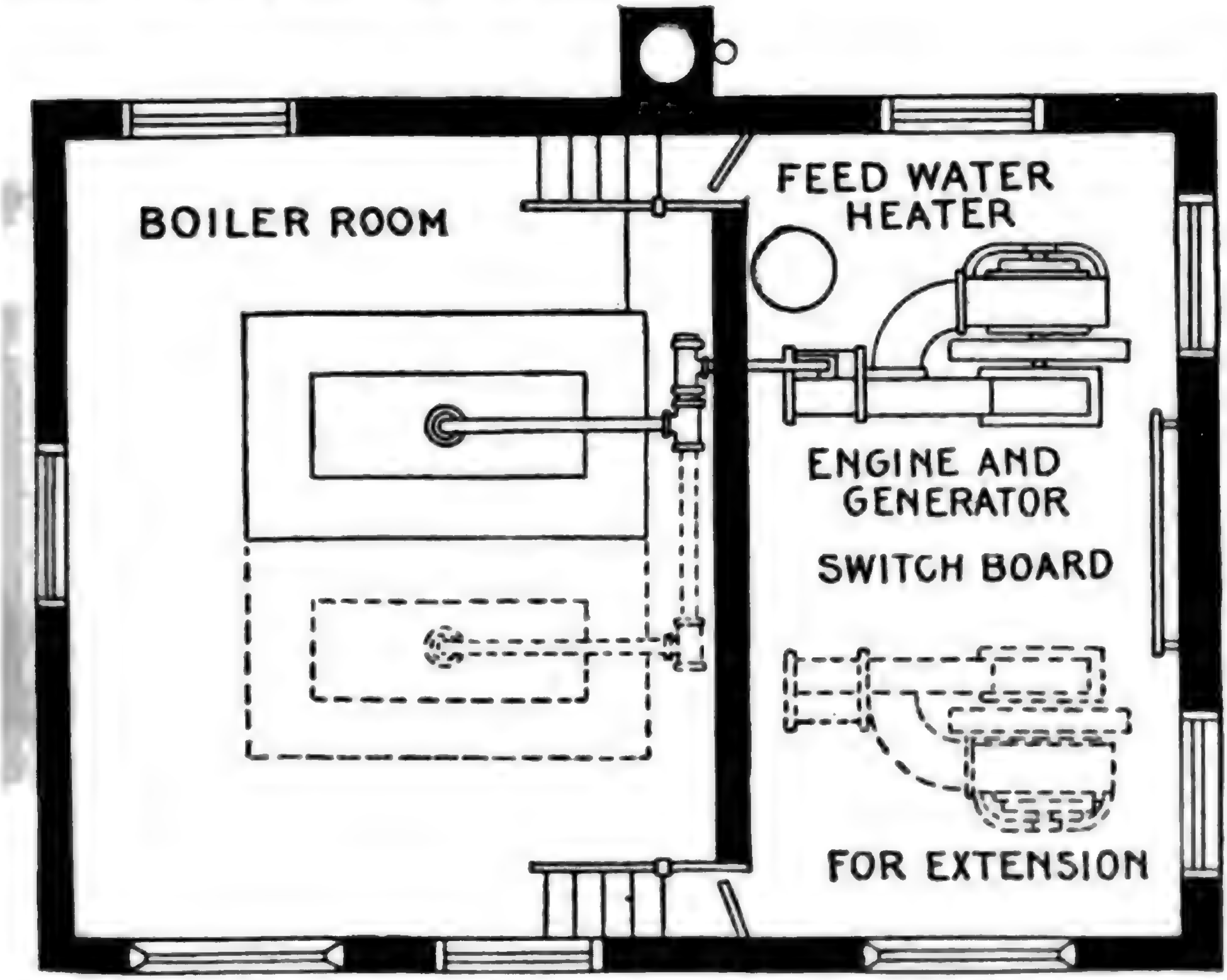
Ques. What are the desirable features of the belt drive?

Ans. High speed generators may be used, thus reducing the first cost, and the multiplicity of speeds and flexibility of the system resulting from the use of a friction clutch.

Thus in fig. 2,720, each pulley may be mounted on the counter shaft O with a friction clutch. A jaw clutch may also be provided at Z, thus permitting the shaft O to be divided into two sections. It is therefore possible by this arrangement to cause either of the engines to drive any one of the generators, or all of them, or both of the engines to drive all of the generators simultaneously.

Ques. Under what condition is the counter shaft belt drive particularly valuable?

Ans. In case of a break down of any one of the engines or enerators, and also when it becomes necessary to clean them ithout interrupting the service.



IG. 2,722.—Plan of station arranged for extension. The space required for a central station depends upon the number and kind of lights to be supplied, and upon the character and arrangement of the machinery. In calculating the size of building required, two things must be carefully considered: first, the building must be adapted to the plant to be installed in the beginning; and second, it must be arranged so that enlargement can be made without disarranging or interfering with the plant already in existence. This is usually best secured by providing for expansion in one or two definite directions, the building being made large enough to accommodate additional units that will be necessary at some future time because of the growth of the community and consequent increased demand for electric current.

Ques. How may the design in fig. 2,720 be modified or the installation of a storage battery?

Ans. If a storage battery be necessary, a partition may be onstructed across the room A, as indicated by the dotted lines, nd the battery installed in the room thus formed.

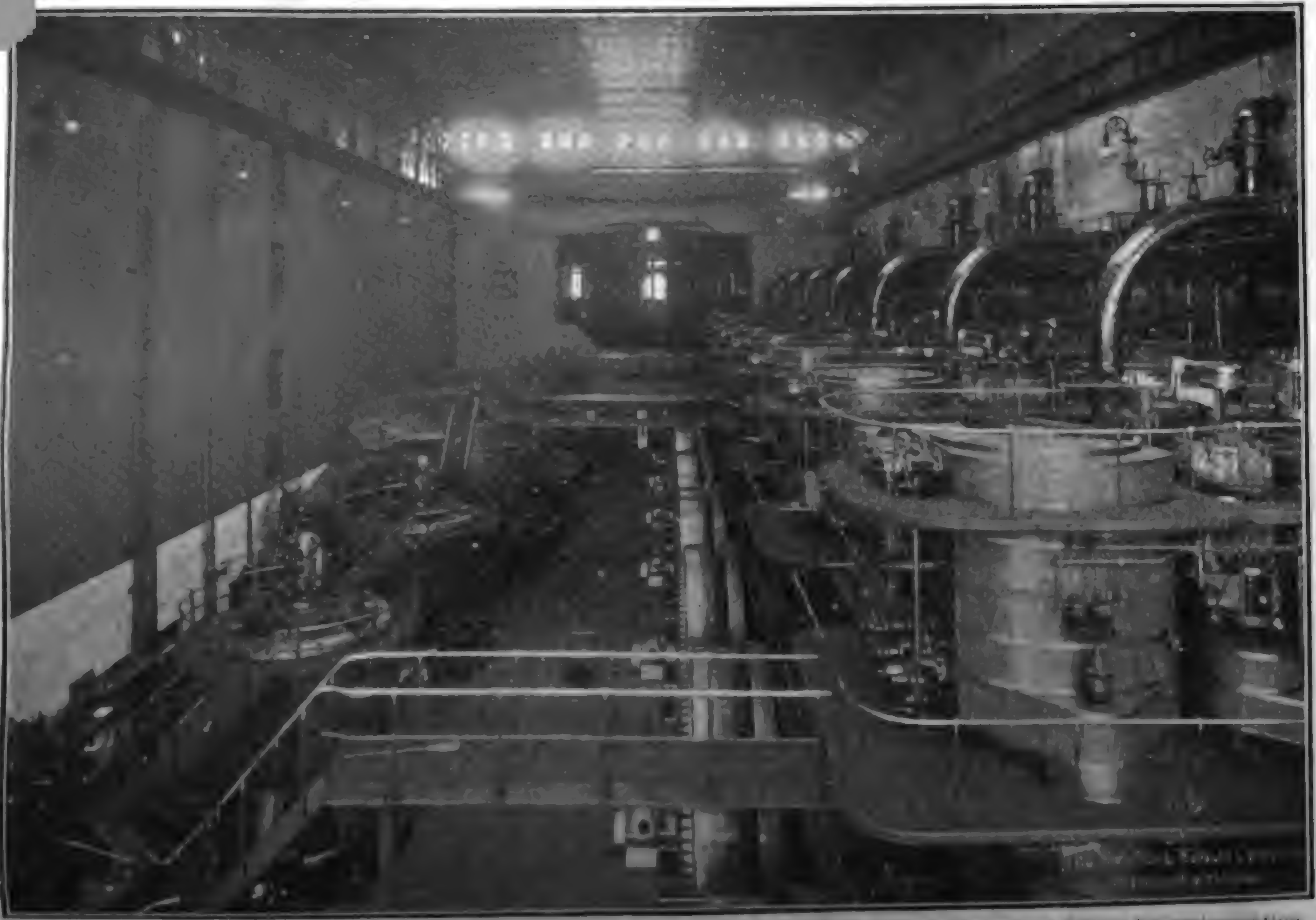


FIG. 2,7[illegible].—Interior of old Waterside station showing at the right, seven 5,000 horse power alternators driven by reciprocating engines, and at the left, a number of turbine units aggregating [illegible] horse power.

Ques. Mention a few details in the general arrangement of the building fig. 2,720.

Ans. Two doors to the room A may conveniently be provided at K and L, the former connecting with the boiler room B, and the latter serving as the main entrance to the station. There is little that need be added to what has already been stated regarding the boiler room B. The door at F provides for the entrance of coal and the removal of ashes, while at P, the pump and heaters may conveniently be located. In the office C, visitors may be received, the station reports made out, bulletins issued from time to time, and whatever engineering problems arise may here be solved on paper by the engineer in charge of the plant. The store room D will be found convenient for various supplies, tools and appliances needed in the operation of the station. These may here be kept under lock and key and the daily waste and loss resulting from carelessness avoided.

Ques. What important point should be noted in locating the engines and boilers?

Ans. They should be so placed that the piping between them will be as short and direct as possible.

Ques. Why?

Ans. The steam pipe should be short to reduce the loss of heat between engine and boiler to a minimum, and both short and direct to avoid undue friction and consequent drop in pressure of the steam in passing through the pipe to the engine.

Entirely too little attention is given to this matter on the part of designers and it cannot be too strongly emphasized that, for economy, the steam pipe between an engine and boiler should be as short and direct as possible, having regard of course, for proper piping methods.

Ques. What should be provided for the steam pipe?

Ans. A heavy covering of approved material should b

placed around the pipe to reduce the loss of heat by radiatio
For this purpose hair felt, mineral wool and asbestos are use

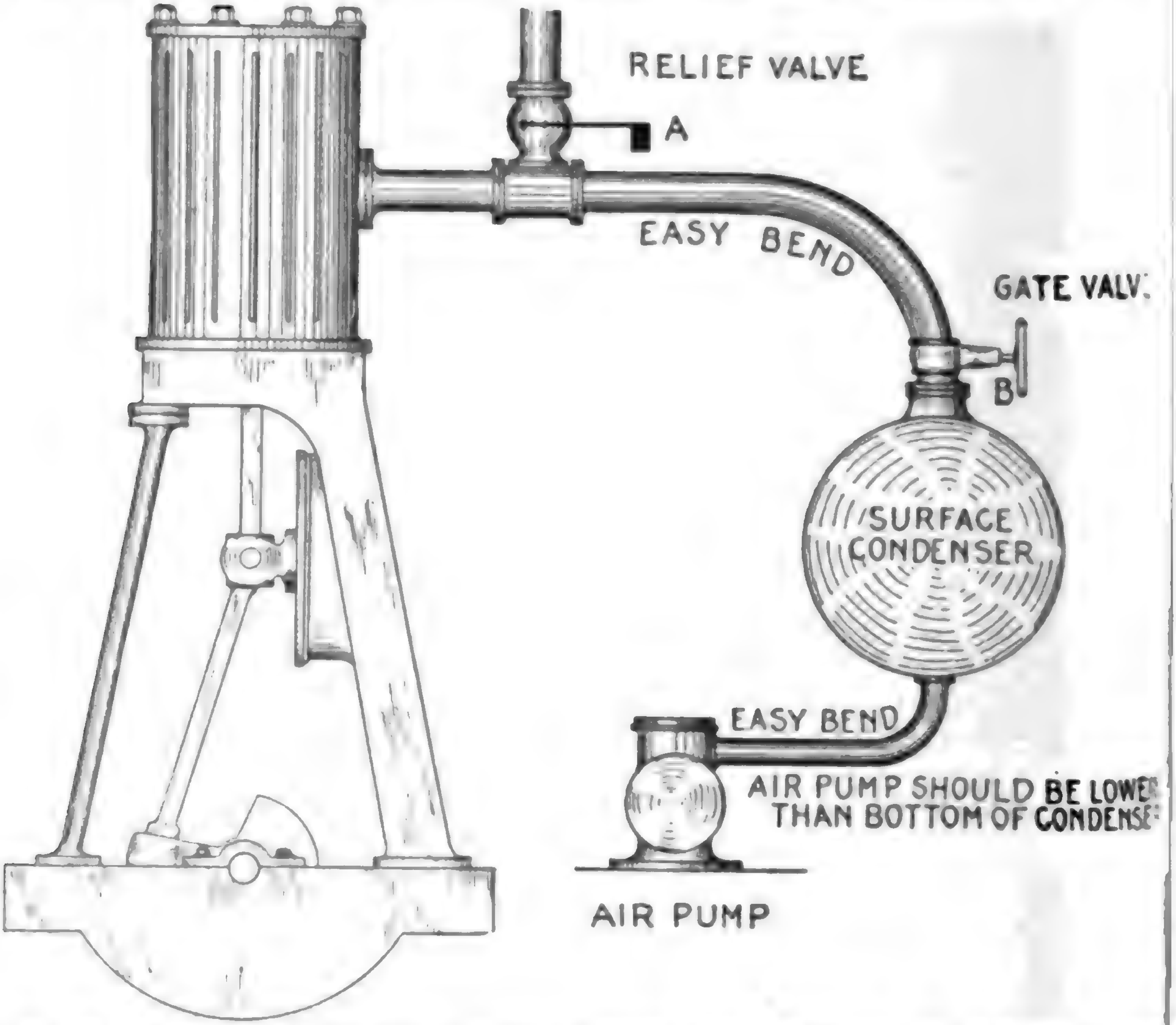

RELIEF VALVE
A
EASY BEND
GATE VALV
B
SURFACE CONDENSER
EASY BEND
AIR PUMP SHOULD BE LOWE
THAN BOTTOM OF CONDENSE
AIR PUMP

FIG. 2,724.—View of engine and condenser, showing how to arrange the piping to good vacuum. *Locate the condenser as near the engine as possible;* **use easy bends** *of elbows; place the pump* **below** *bottom of condenser so the water will drain to pump.* A is a relief valve, for protection in case the condenser become flooded through failur the pump, and at B is a gate valve to shut off condenser in case atmospheric exhaust desired to permit repairs to be made to condenser during operation. **A water seal** be maintained on the relief valve and **special attention** *should be given to the stuffing* of the gate valve **to prevent air leakage.** *The discharge valve of the pump should water sealed.*

Ques. How should the piping be arranged between th engine and condenser, and why?

Ans. It should be as short and direct as possible; especial should elbows be avoided so that the back pressure on the engi piston will be reduced as near as can be to that of the condens

That is to say, in order to get nearly the full effect of the vacuum in the condenser the frictional resistance of the piping should be reduced to a minimum.

Where 90° turns are necessary, easy bends should be used instead of sharp elbows. The force of this argument must be apparent by noting the practice of steam turbine builders of placing the turbine right up against the condenser, and remembering that a high vacuum is necessary to the economical working of a turbine. See fig. 1,445, page 1,182.

Ques. What are the onsiderations respectng the number and ype of engine to be sed?

Ans. In the illustration g. 2,720, two engines M nd M′ are employed, one elted to each end of the ountershaft O. These enines should be of similar identical pattern; for a nall output they may be ther simple or compound, the conditions of fuel exenditure may dictate, but the output be large, triple pansion engines or turnes are advisable.

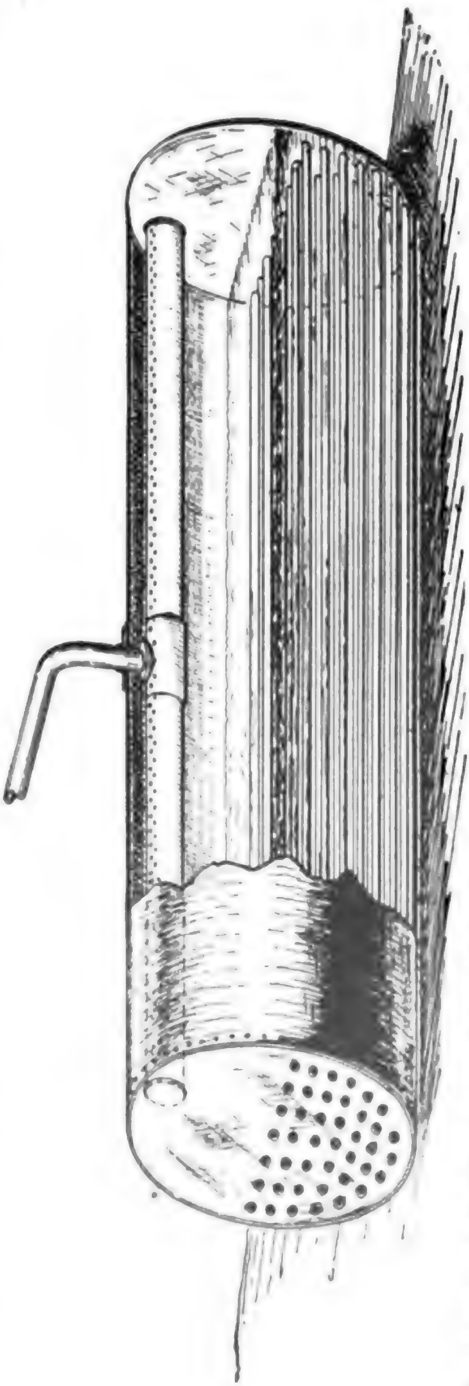


FIG. 2,725.—"Dry pipe" for horizontal boiler; it is connected to the main outlet and its upper surface is perforated with small holes, the far end being closed. With this arrangement steam is taken from the boiler over a large area, so that it will contain very little moisture. *All horizontal boilers without a dome should be fitted with a dry pipe;* most engineers do not realize the importance of obtaining dry steam for engine operation.

Corliss or similar slow speed engines may advantageously be used in either case. In all cases the engine should be run condensing unless the cost for circulating water is prohibitive; even in such cases cooling towers may be installed and effect a saving.

In operation, during the greater part of the day, one engine running two or perhaps three of the generators, will carry the load, but when the load is particularly heavy, as in the morning and evening, both engines and all the generators may be required to meet the demands.

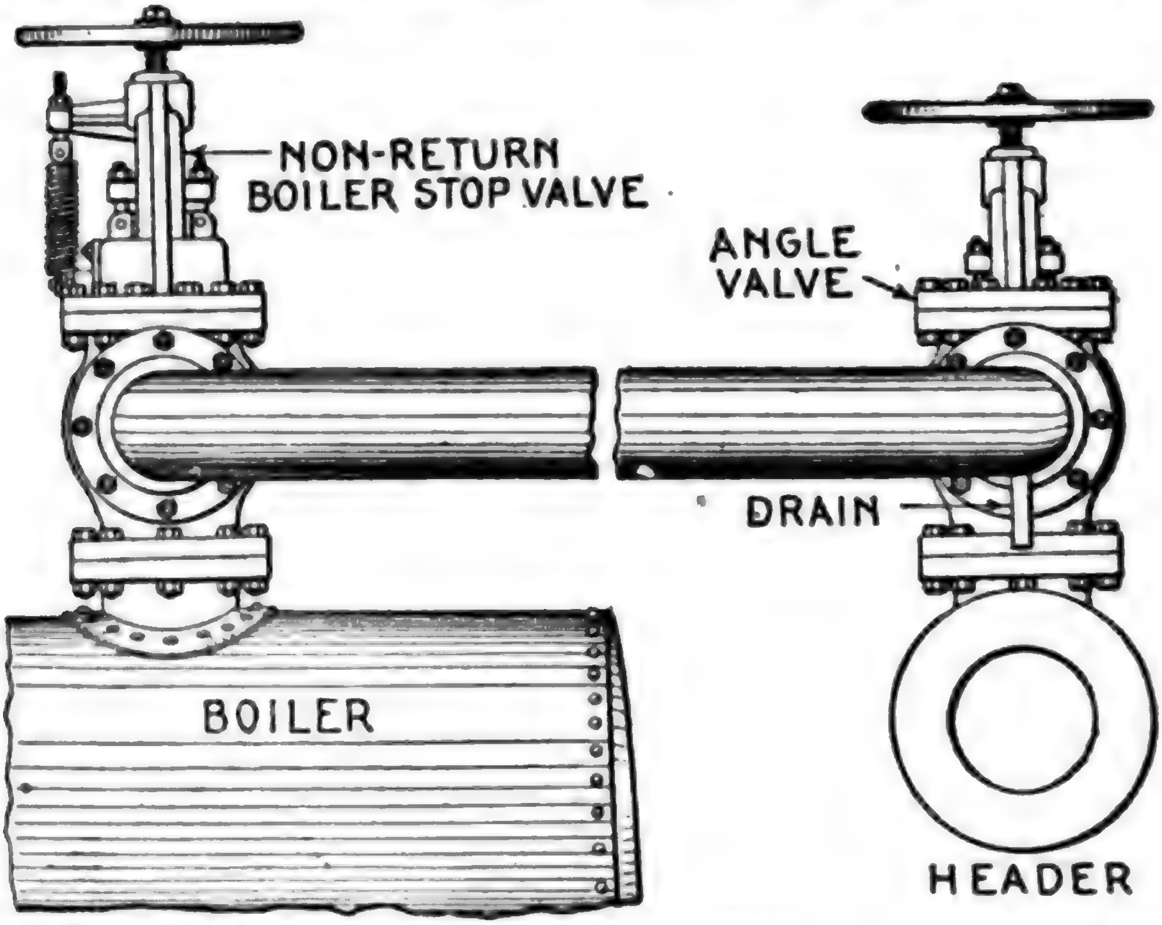


FIG. 2,726.—Method of connecting a header to a battery of boilers. Where two or more boilers are connected to a single header, the use of a reliable non-return boiler stop valve is necessary, and in some countries their installation is compulsory. A non-return boiler stop valve will instantly close should the pressure in the boiler to which it is attached suddenly decrease below that in the header, and thereby prevent the entrance of steam from the other boilers of the battery. This sudden decrease in pressure may be caused by a ruptured fitting or the blowing out of a tube, in which event an ordinary stop valve taking the place of a non-return boiler stop valve would be inadequate, as the loss of steam from the other boilers of the battery would be tremendous before an ordinary valve could be reached and closed, assuming that it would be possible to do so, which in the majority of cases it is not. Should it be desired to cut out a boiler for cleaning or repairs, the non-return boiler stop valve will not permit steam to enter the boiler from the header, even should the handwheel be operated for this purpose, as it cannot be opened by hand, but can, however, be closed. A non-return boiler stop valve should be attached to each boiler and connected to an angle valve on the header. A pipe bend should be used for connecting the valves, as this will allow for expansion and contraction. The pipe should slope a trifle downward toward the header and a suitable drain provided. This drain should be opened and all water permitted to escape before the angle valve is opened, thereby preventing any damage due to water hammer.

By exercising a little ingenuity in shifting the load on different machines at different times, both engines and dynamos, may readily be cleaned and repaired without interrupting the service.

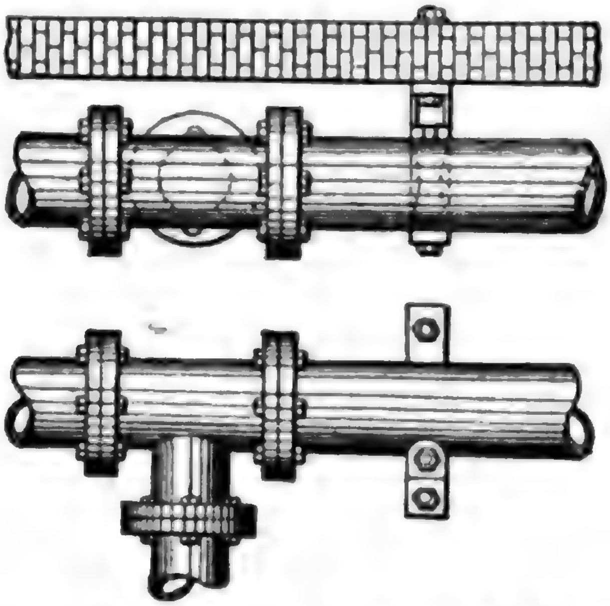
Ques. For economy what kind of steam should be used?

Ans. Super-heated steam.

The saving due to the use of superheated steam is about 1% for every ten degrees Fahr. of super-heat. It should be used in all cases.

Ques. How should the machines be located?

Ans. Sufficient space should be allowed between them that cleaning and repairing may be done easily, quickly and effectually.



FIGS. 2,727 and 2,728.—Method of preventing vibration and of supporting pipes. The figures show top and side views of a main header carried in suitable frames fitted with adjustable roller. While the pipe is illustrated as resting on the adjustable rollers, nevertheless the rollers may also be placed at the sides or on top of the pipe to prevent vibration, or in cases where the thrust from a horizontal or vertical branch has to be provided for. This arrangement will take care of the vibration without in any way preventing the free expansion and contraction of the pipe.

Ques. How should the switchboard be located?

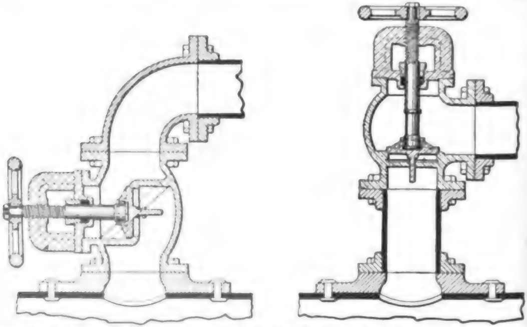
Ans. In fig. 2,720, the switchboard H is mounted against the wall dividing the room A from the room B, and is in line with the machines.

The advantages arising from a switchboard thus installed are, that the switchboard attendant working thereon can obtain at any time an unobstructed view of the performance of each individual machine, and he has in consequence a much better control of them; then, too, while he is engaged at the engines or generators he can also see the measuring instruments on the switchboard, and ascertain approximately the readings upon them.

In cases of emergency it is sometimes necessary for the engineer in charge of a plant to be in several places at the same time in order to prevent an accident, and that this seemingly impossibility may be approximated as nearly as possible, it is essential that the controlling devices be located as closely together as is consistent, and that no moving belt or pulley intervene between them.

These conditions are well satisfied in fig. 2,720, and owing to the short distances between the generators and the switchboard the drop of voltage in each of the conducting wires between them will be low.

This latter advantage is worthy of notice in a station generating large currents at a low pressure. To offset the advantages just mentioned, the location of the switchboard in line with the machines introduces an element of danger to the switchboard, its apparatus, and the attendant, on account of the possible bursting of a flywheel or other parts of the machines from centrifugal force.



FIGS. 2,729 and 2,730.—Points on placing stop valves. The first and most important feature is to ascertain whether the valve will act as a water trap for condensed steam. Fig. 2,729 illustrates a common error in the placing of valves, as this arrangement permits of an accumulation of condensed steam above the valve when closed, and should the engineer be careless and open the valve suddenly, serious results might follow owing to water-hammer. Fig. 2,730 illustrates the correct method of placing the valve. It sometimes occurs, however, that it is not convenient to place the valve as shown in fig. 2,730 and that fig. 2,729 is the only manner in which the valve can be placed. In such cases, the valve should have a drain, and this drain should always be opened before the large valve is opened.

If the switchboard be placed in the dotted position at H′, or, in fact, at the opposite end of the room A, the damage to life and property that might result from the effects of centrifugal force would be eliminated, but in place thereof would be the disadvantages of an obstructed view of the machines from the switchboard, an obstructed view of the switchboard from the machines, inaccessibility between these two, and a greater drop of voltage in the majority of the conducting wires between the generators and the switchboard.

Ques. Describe a second arrangement of station with belt drive and compare it with the design shown in fig. 2,720.

Ans. A floor plan somewhat different from that presented in fig. 2,720 is shown in fig. 2,731. Here a belt drive is employed, but no countershaft is used. Each generator, therefore, is dependent upon its respective engine, and in consequence the flexibility obtained by the use of a countershaft is lost. On the other hand, there is less loss of mechanical power between the

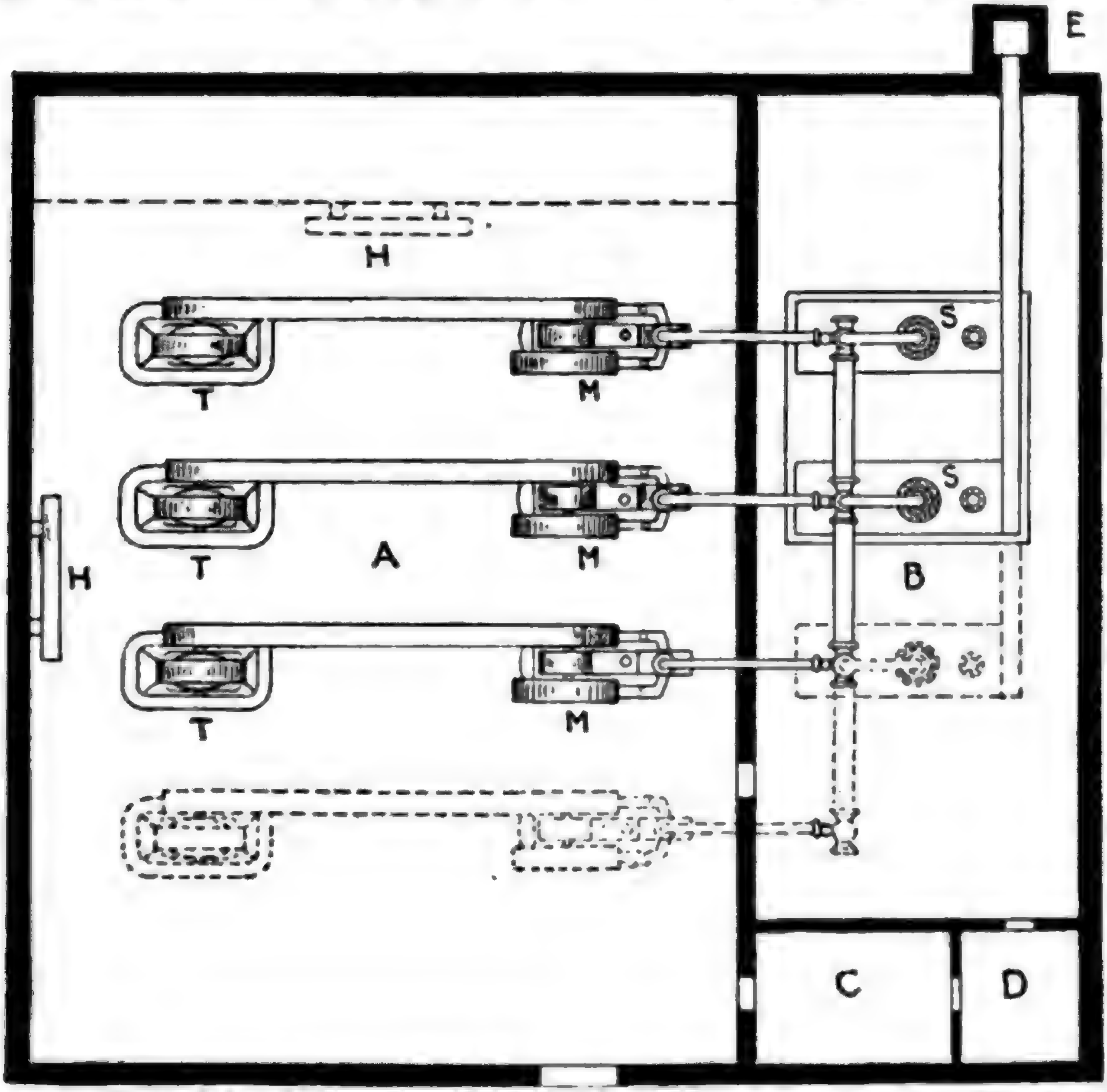


FIG. 2,731.—Plan of electrical station with belt drive without counter shaft. The installation here represented consists of two boilers, S, etc., and three sets of engines and generators, T, M, etc. Sufficient allowance has been made in the plans, however, for future increase of business, as additional space has been provided for an extra engine and generator set, as indicated by the dotted lines.

engines and generators in the driving of the latter, and less floor space is necessary in the room A. If, however, the floor area of this room be made the same as in the previous arrangement and the same number of machines are to be installed, they may be spaced further apart, affording in consequence considerably more room for cleaning and repairing them.

In operation, the normal conditions should be such that any two of the engine and generator sets may readily carry the average load, the third set to be used only as a reserve either to aid the other two when the load is unusually heavy or to replace one of the other sets when it becomes necessary to clean or repair the latter.

The switchboard may perhaps be best located at H, as a similar position on the opposite side of the room A would bring it beneath one or more of the steam pipes and thus endanger it should a possible leakage occur from these pipes. If located at H, however, it will be in line with the machines, and therefore will be subject to the disadvantages previously mentioned for such cases; consequently it might be as well to place it at the further end of the room, either against the partition (shown dotted) of the storage battery room if this be built, or else (if no storage battery is to be installed), against the end wall itself. The nearer end of the room A would not be very desirable for the switchboard installation on account of being so far removed from the machines, and therefore more or less inaccessible from them. Outside of what has now been mentioned, the division of the floor plan and the arrangement therein is practically the same as in fig. 2,720, accordingly what has already been stated regarding the former installation applies, therefore, with equal force to the present installation.

Ques. Describe a plant with direct drive.

Ans. This type of drive is shown in fig. 2,732. Each engine is directly connected to a generator, that is, the main shafts of both are joined together in line so that the generator is driven without the aid of a belt.

Ques. What is the advantage of direct drive?

Ans. The great saving in floor space, which is plainly shown in fig. 2,732, the portion A′ representing the saving which results over the installations previously illustrated in figs. 2,720 and 2,731.

Ques. How could the floor space be further reduced?

Ans. By employing vertical instead of horizontal engines.

Ques. What should be done before drawing the plans for the station?

Ans. The types of the various machines and apparatus to be installed should, as nearly as possible, be selected in advance so that their approximate dimensions may serve as a guide in drawing up the plans of the building.

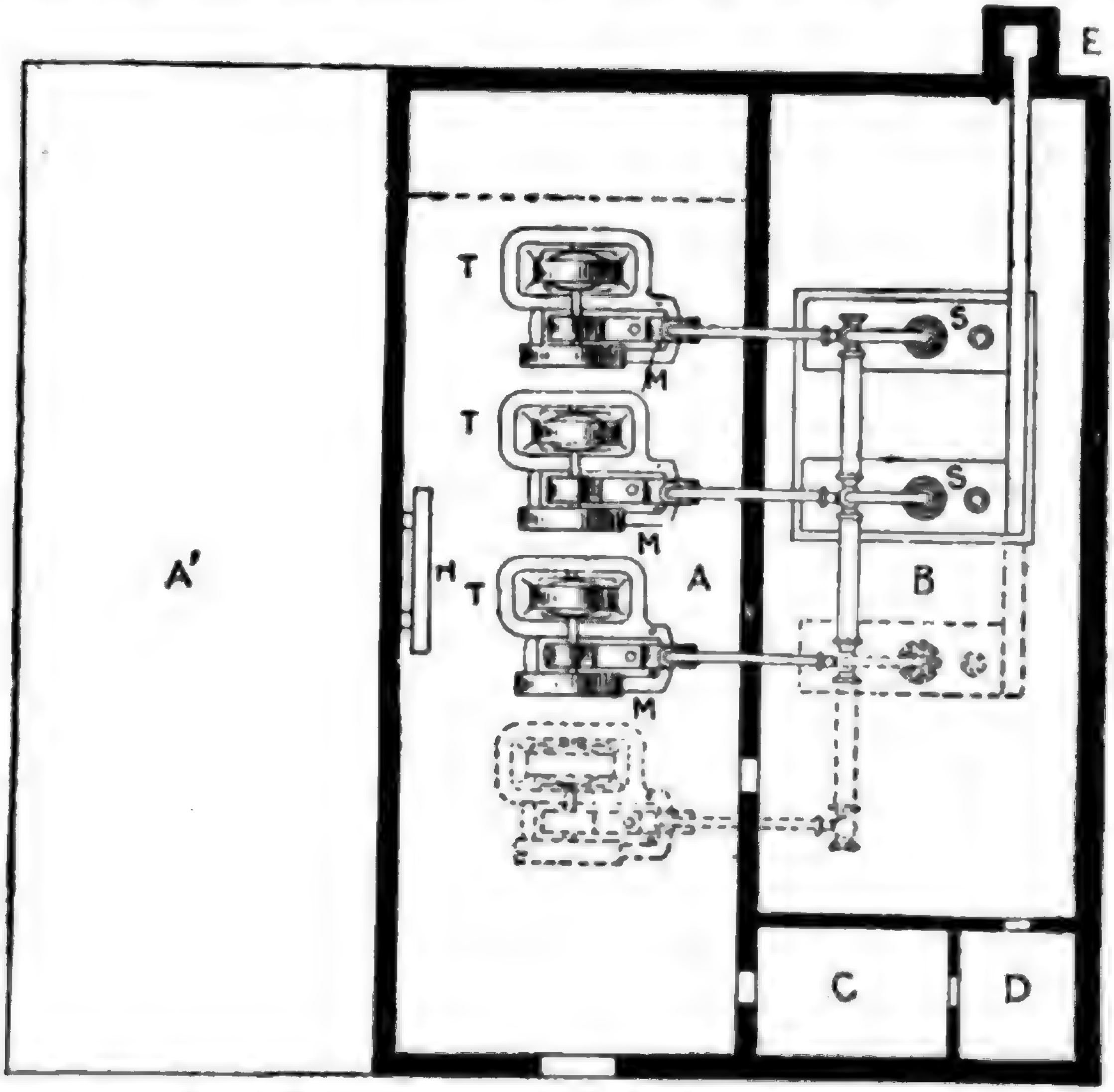


FIG. 2,732.—Plan of electrical station containing direct connected units. As shown, space is provided for an extra boiler and engine and generator set, as indicated by the dotted lines. Space also exists for a storage battery room if necessary, and the partition dividing this room from the engine and dynamo room is shown by a dotted line as in previous cases.

Owing to the great difference in these dimensions for the various types, and in fact for the same types as manufactured by different concerns, no definite rules regarding the necessary space required here be given. In a general way, however, the author has endeavored to indicate by the drawings the relative amounts of space that ordinarily would be considered sufficient.

Ques. What is the disadvantage of direct drive?

Ans. A more expensive generator is required because it must run at the same speed as the engine, which is relatively low as compared with that of a belted generator.

Station Construction.—The construction or rearrangement of the building intended for the plant is a problem that under ordinary conditions would be solved by an architect, or at least by an architect with the assistance of an electrical or mechanical engineer, still there are many installations where the electrical engineer has been compelled to design the building.

In such instances he should be equipped with a general knowledge of the construction of buildings.

Foundations.—The foundation may be either natural or artificial; that is, it may be composed of rock or soil sufficiently solid to serve the purpose unaided, or it may be such as to require strengthening by means of wood or iron beams, etc. In either case any tendency toward a considerable settling or shifting of the foundation due to the action of water, frost, etc., after the station has been completed must be well guarded against. To this end special attention should be given to the matter of drainage.

Ques. How should the foundation be constructed for the machines?

Ans. The foundations constructed for the machines should be entirely separate from that built for the walls of the building so that the vibrations of the former will not affect the latter.

If there be several engines and dynamos to be installed, it is best to construct two foundations, one for the engines and one for the dynamos. If, however, there be considerable distance between the units, it may be advisable to build a separate foundation for each engine and for each dynamo. The material of which these foundations are composed should if the machines be of 20 horse power or over, possess considerable strength and be impervious to moisture. Brick, stone and concrete are desirable for the purpose, and only the best quality of cement mortar should be employed. Care must be taken that lime mortar is not used in place of cement mortar, as the former is not well adapted to withstand the vibrations of the machines without crumbling.

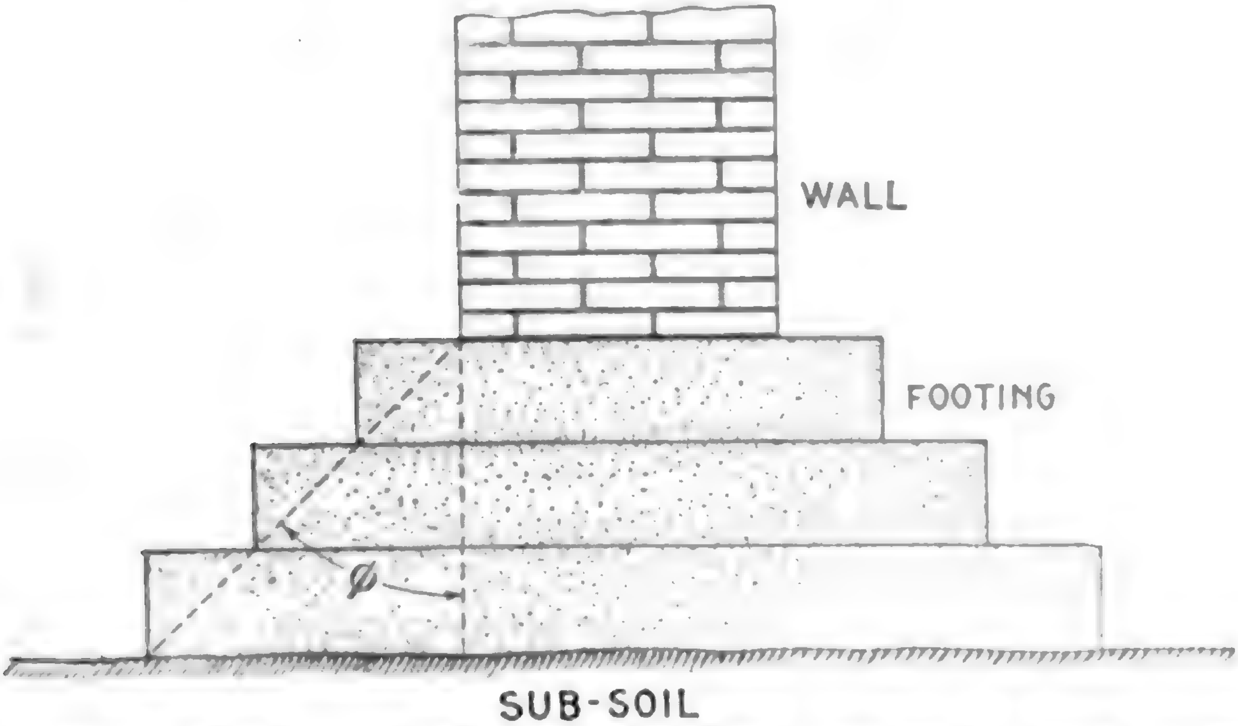


Fig. 2,733.—Angle for foundation footing. In ordinary practice the footing courses upon which the walls of the building proper rest, consist of blocks or slabs of stone as large as are available and convenient to handle. Footings of brick or concrete are also used in very soft soils; footings consisting of timber grillage are often employed. A grillage of iron or steel beams has also been used successfully. The inclination of the angle ϕ, of footing should be about as follows: for metal footings 75°; for stone, 60°; for concrete, 45°; for brick, 30°. Damp proof courses of slate, or layer of asphalt are laid in or on the foundations or lower walls to prevent moisture arising or penetrating by capillary attraction.

Ques. Describe a method of constructing foundations.

Ans. An excavation is made to the desired depth and a form inserted corresponding to the desired dimensions for the foundation. A template is placed on top locating all the centers, with iron pipes suspended from these centers, two or three sizes arger than the anchor bolts. At the lower end of the pipes are core boxes. Concrete is poured into the mould thus formed.

and when hard, the forms are removed thus leaving the solid foundation. The anchor bolts are inserted through the pipes and passed through iron plates at the lower end as shown in fig. 2,734, being secured by nuts. By using pipe of two or three bolt diameters a margin is provided for adjustment so the bolts will pass through the holes in the frame of the machine thus allowing for any slight errors in laying out the centers on the template.

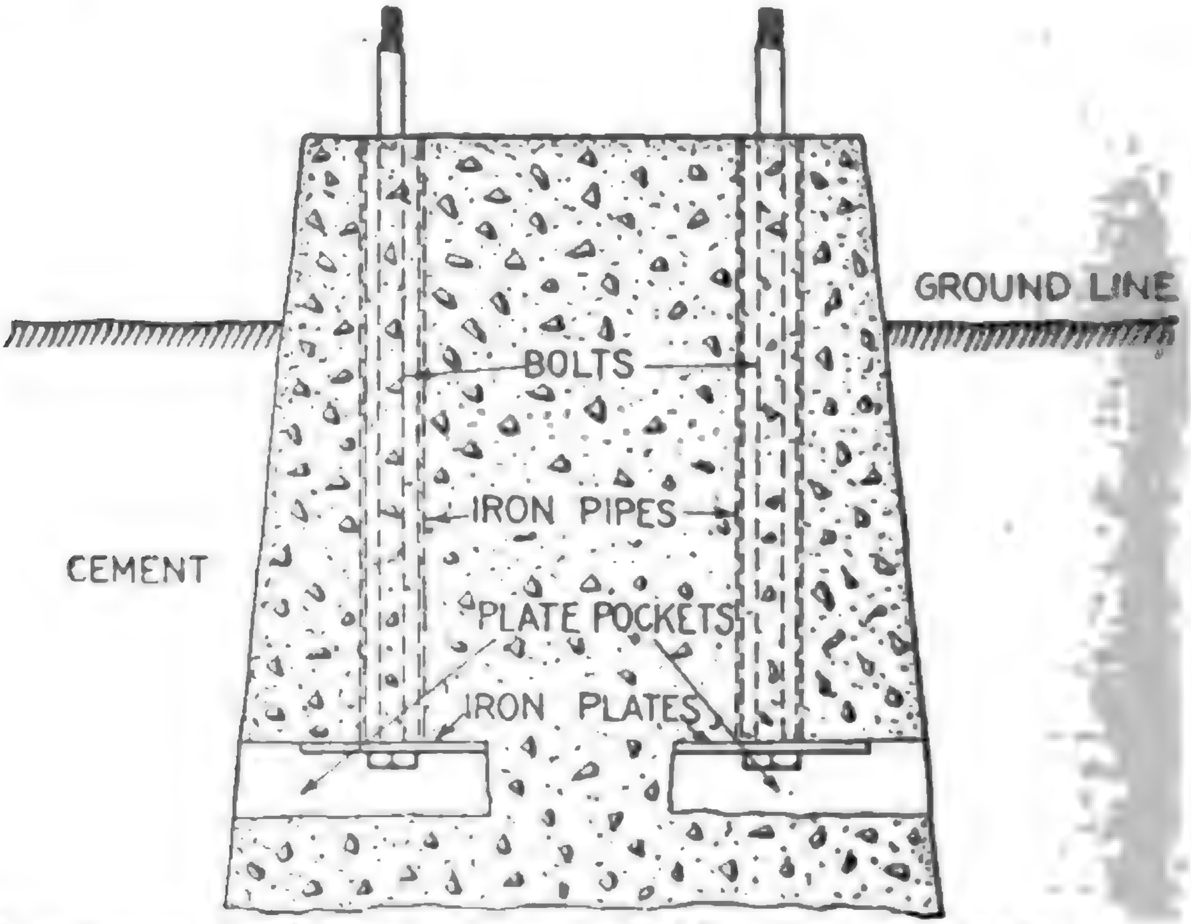
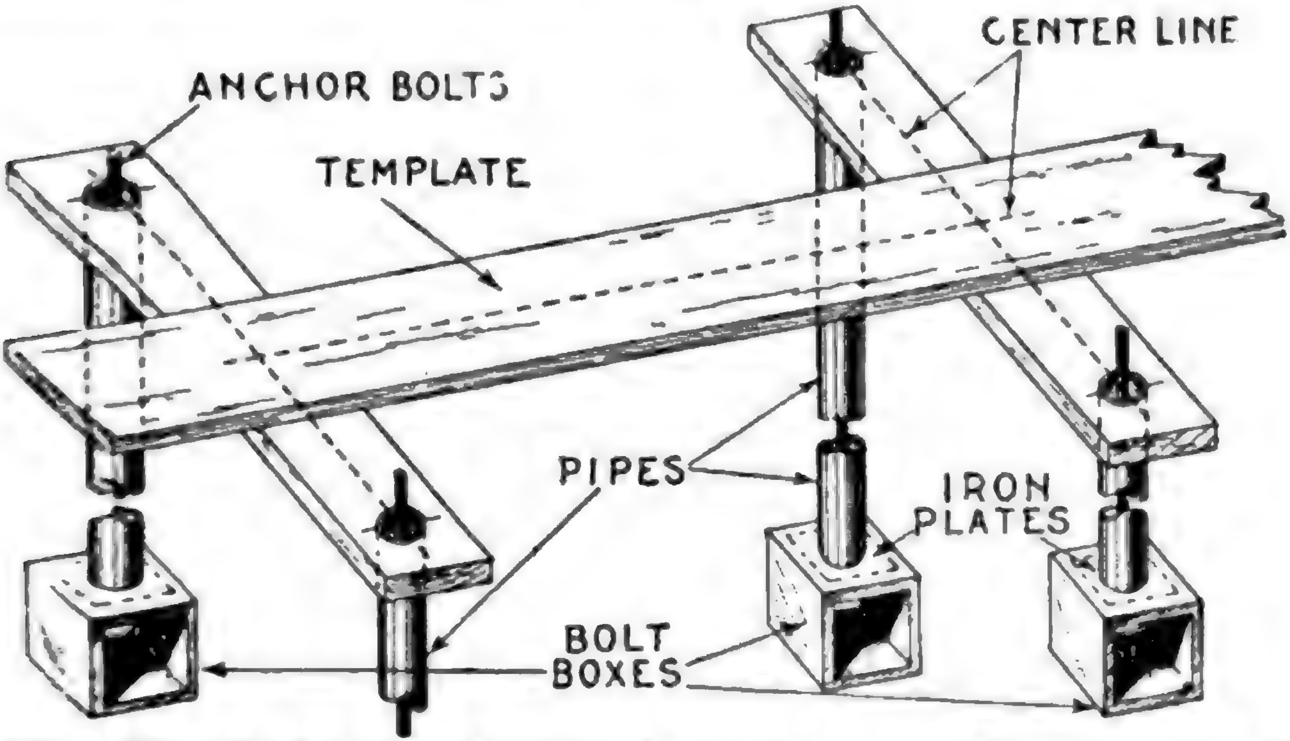


Fig. 2,734.—Concrete foundation showing method of installing the anchor bolts.

Ques. What is the object of the openings in the bottom of the foundation?

Ans. In case of a defective bolt it may be replaced by a new one without injury to the foundation.

Walls.—Regarding the material for the walls of the station iron, stone, brick and wood may be considered. Of these, iron in the form of sheets or plates would be entirely fireproof, but ing itself a conductor would introduce difficulties in main- ining a high insulation resistance of the current carrying rcuits; it would also make the building difficult to heat in inter and to keep cool in summer. Stone in the form of lime- one, granite or sandstone, as a building material is desirable r solidity and attractiveness; it is also fireproof and an insu- tor, but the high cost of such a structure for an electrical ation usually prohibits its use except in private plants or in ectrical stations located in large cities.



2,735.—View showing part of template for locating anchor bolt centers, pipes through which the bolts pass and bolt boxes at lower end of bolts. The completed foundation is shown in fig. 2,734, with template removed. The template is made of plain boards upon which the center lines are drawn, and bolt center located. Holes are bored at the bolt centers to permit insertion of the pipes as shown.

Brick is a good material and is readily obtained in nearly all rts of the country; it is comparatively cheap, and is also an sulating and fireproof material. The bricks selected for this rpose should possess true sharp edges, and be hard burned.

Ques. What are the features of wood?

Ans. Wood forms the cheapest material that can be used r the walls of electrical stations, and it usually affords satis- ction, but has the disadvantage of high fire risk.

Roofs.—In fig. 2,736 is shown one form of construction fo the roof of an electrical station. The end view here presente shows the upper portion of the walls at B and D; these suppor the iron trusses C, and the roof proper MN. In many station there is provided throughout the length of the building, a monito or raised structure on the peak of the roof for ventilation an light. The end view of the monitor is shown at S in the figure its sides should be fitted with windows adjustable from the floor

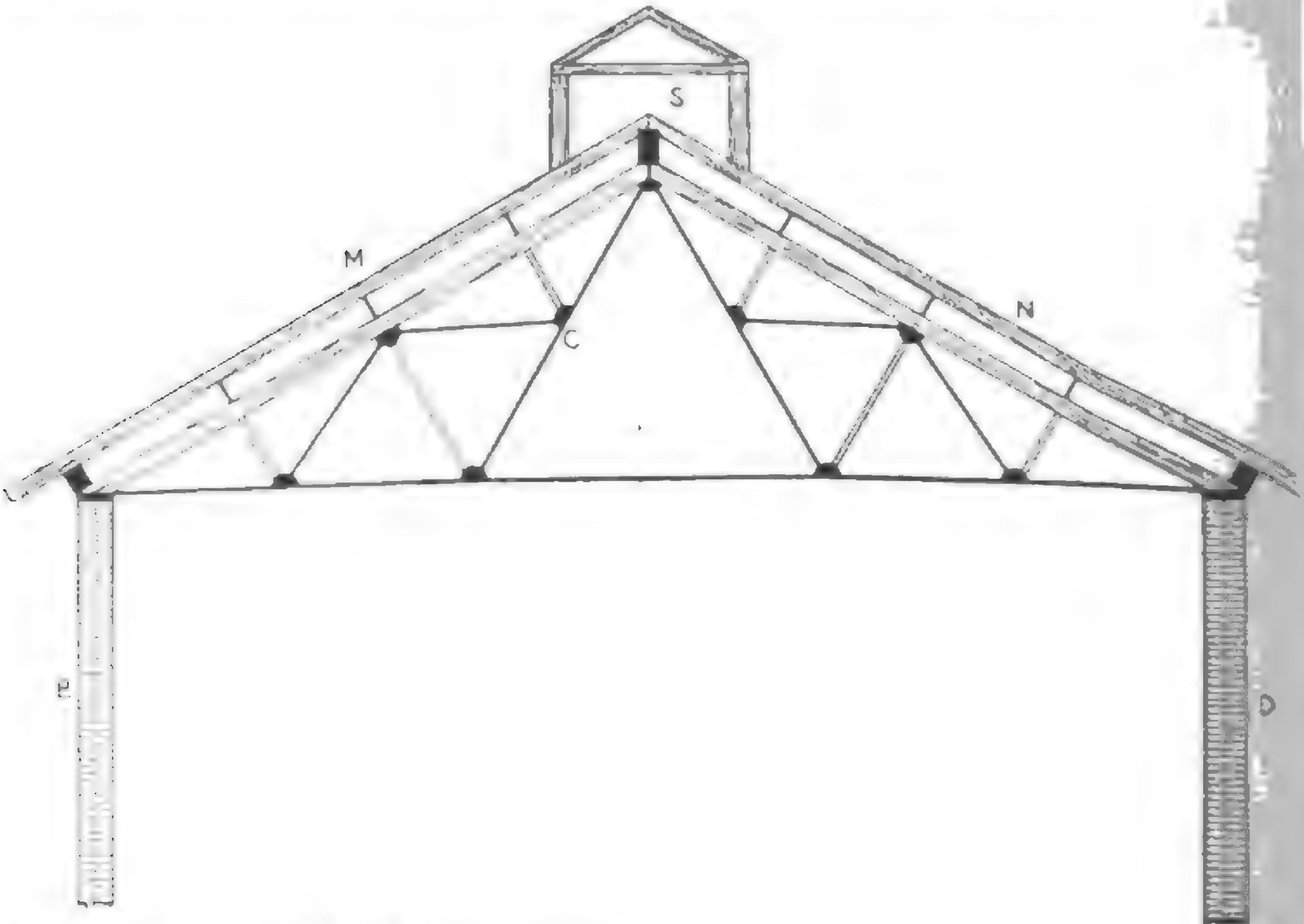


FIG. 2,736.—[illegible] of roof construction.

Floors.—The floor of the station should be so designed tha it will be capable of supporting a reasonable weight, but as th weights of the machines are borne entirely by their respecti foundations the normal weight upon the floor will not be grea for short periods, however, it may be called upon to support on or two machines while they are being placed in position o nterchanged, and due allowance must be made for such ccurrences.

Station floors for engine and dynamo rooms are, as a rule, onstructed of wood. Where very high currents are generated, owever, insulated floors of special construction mounted on lass are necessary as a protection from injurious shocks. Brick, oncrete, cement, and other substances of a similar nature are bjectionable as a floor material for engine and dynamo rooms n account of the grit from them, caused by constant wear, eing liable to get into the bearings of the machines.

THEORETICAL DRAFT PRESSURE IN INCHES OF WATER IN A CHIMNEY 100 FEET HIGH

(For other heights the draft varies directly as the height)

Temperature in Chimney, Fahr.	TEMP. OF EXTERNAL AIR. (BAROMETER 30 INCHES)										
	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°
[illegible]	.453	.419	.384	.353	.321	.292	.263	.234	.209	.182	.157
[illegible]	.488	.453	.419	.388	.355	.326	.298	.269	.244	.217	.192
[illegible]	.520	.488	.451	.421	.388	.359	.330	.301	.276	.250	.225
[illegible]	.555	.528	.484	.453	.420	.392	.363	.334	.309	.282	.257
[illegible]	.584	.549	.515	.482	.451	.422	.394	.365	.340	.313	.288
[illegible]	.611	.576	.541	.511	.478	.449	.420	.392	.367	.340	.315
[illegible]	.637	.603	.568	.538	.505	.476	.447	.419	.394	.367	.342
[illegible]	.662	.638	.593	.563	.530	.501	.472	.443	.419	.392	.367
[illegible]	.687	.653	.618	.588	.555	.526	.497	.468	.444	.417	.392
[illegible]	.710	.676	.641	.611	.578	.549	.520	.492	.467	.440	.415
[illegible]	.732	.697	.662	.632	.598	.570	.541	.513	.488	.461	.436
[illegible]	.753	.718	.684	.653	.620	.591	.563	.534	.509	.482	.457
[illegible]	.774	.739	.705	.674	.641	.612	.584	.555	.530	.503	.478
[illegible]	.793	.758	.724	.694	.660	.632	.603	.574	.549	.522	.497
[illegible]	.810	.776	.741	.710	.678	.649	.620	.591	.566	.540	.515
[illegible]	.829	.791	.760	.730	.697	.669	.639	.610	.586	.559	.534

Where there are no moving parts, however, as in the boiler oom, the materials just mentioned possess no disadvantages nd are preferable to wood on account of being fireproof.

Chimneys.—These are generally constructed of brick and ron, sometimes of concrete. Iron chimneys cost less than brick

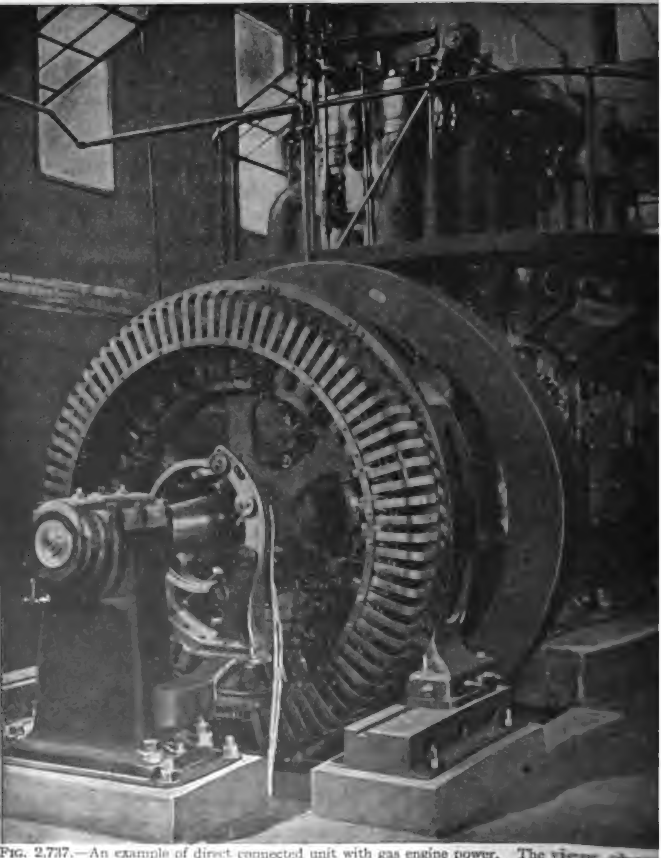
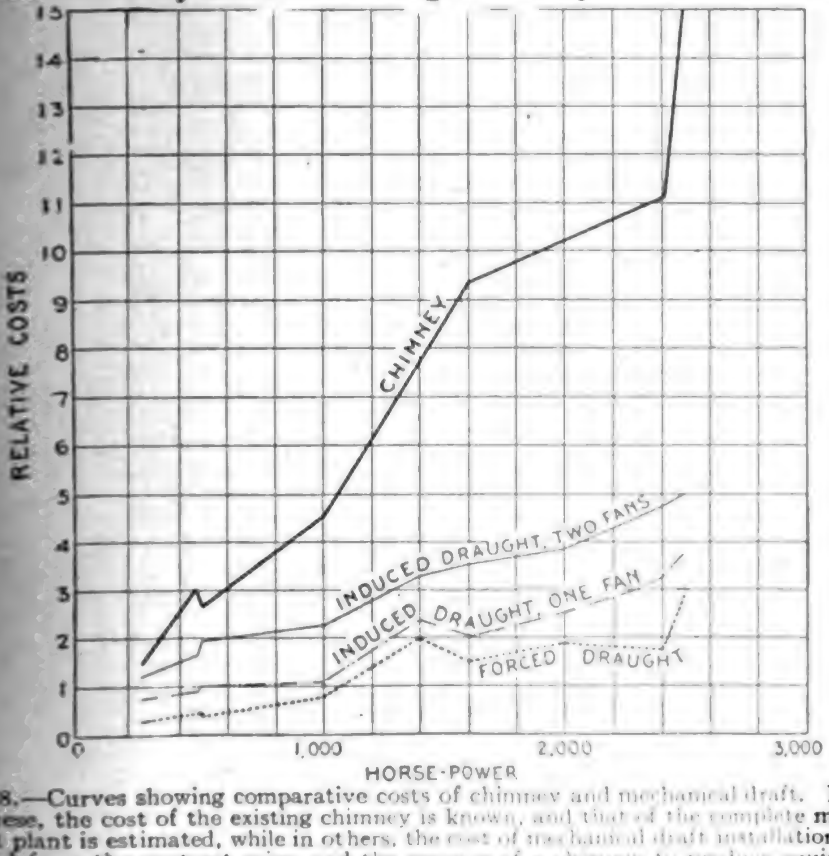


FIG. 2,737.—An example of direct connected unit with gas engine power. The view show Westinghouse 200 kva., 4,000 volt, three phase, 60 cycle alternator direct connected gas engine.

himneys, necessitate less substantial foundations, and are e from the liability of cracking. They must be painted to revent corrosion, are less substantial, and lose considerably nore heat by radiation than do brick chimneys.

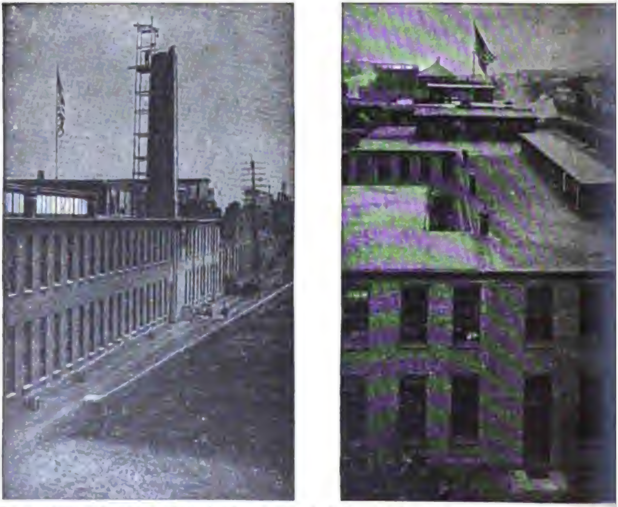
Both brick and iron chimneys, require an inner wall or lining f brick, which forms the flue proper, and in order that this wall e not cracked by sudden cooling an air space is left between it d the outer wall. In a brick chimney the inner wall need not tend much beyond half the height of the chimney, but when n is used it should reach to the top.



2,798.—Curves showing comparative costs of chimney and mechanical draft. In certain f these, the cost of the existing chimney is known, and that of the complete mechanical draft plant is estimated, while in others, the cost of mechanical draft installation is determined from the contract price, and the expense of a chimney to produce equivalent results is calculated. Costs are shown for both single, forced and induced engine driven fans and for duplex engine driven plants, in which either fan may serve as a relay. An apparatus of the latter type is the most expensive, and finds its greatest use where conomizers are employed.

Ques. Upon what does the force of natural draugh in a chimney depend?

Ans. It depends upon the difference between the weight the column of hot gases inside the chimney and the weight a like column of the cold external air.



FIGS. 2,739 and 2,740.—Substituting mechanical draught in place of chimney. The rel proportions of a brick chimney, and of the smoke pipe required when mechanical dra introduced are forcibly shown in the illustrations, which show the works of the Sturtevant Co., at Jamaica Plain, Mass. The removal of the boilers to a position to distant from the existing chimney to permit of its longer fulfilling its office, led to substitution of an induced draft fan and the subsequent removal of the chimney. present stack or smoke pipe, barely visible in fig. 2,740, extends only 31 feet above ground, and no trouble is experienced from smoke.

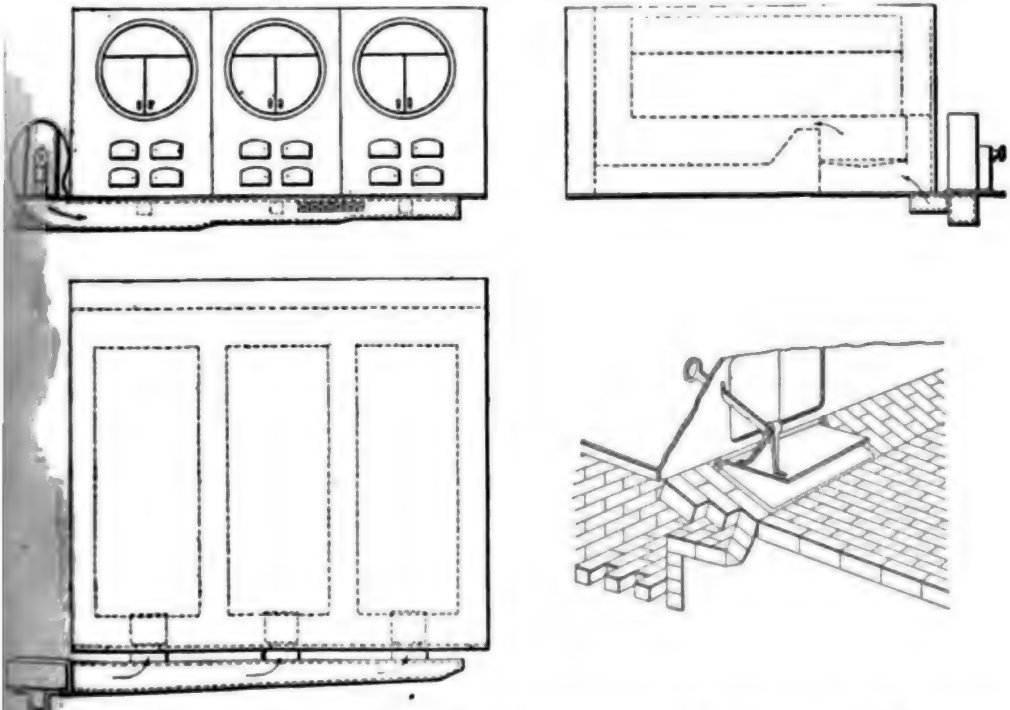
Ques. How is the intensity of the draught expressed

Ans. In terms of the number of inches of a water colu sustained by the pressure produced.

Ques. Are high chimneys necessary?

Ans. No.

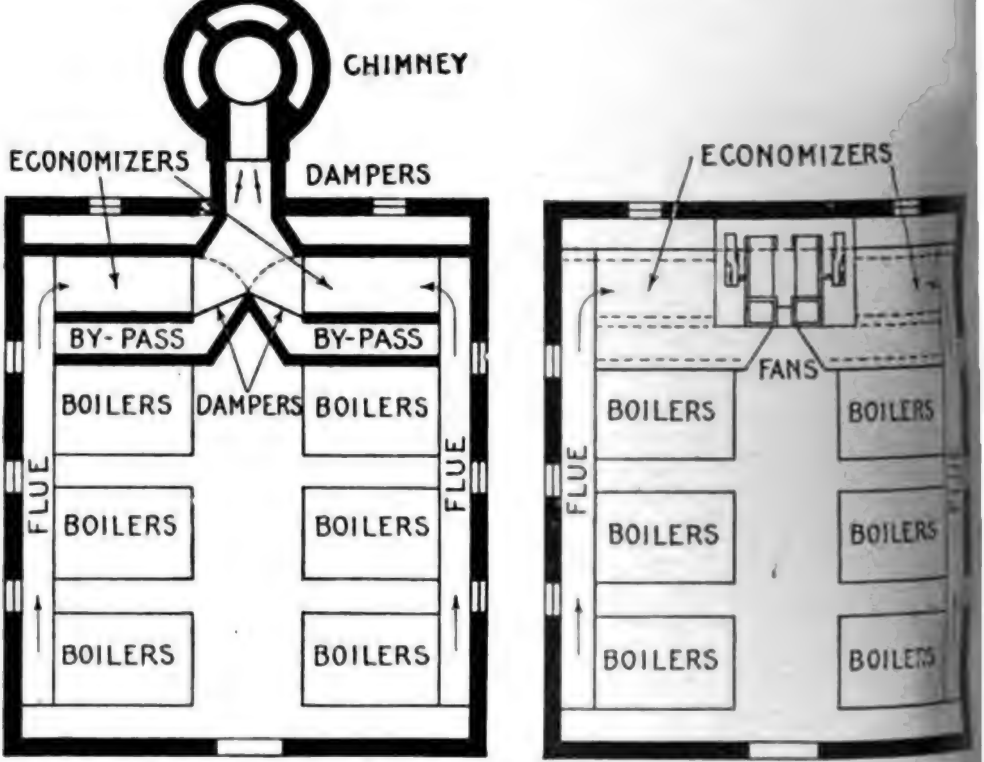
Chimneys above 150 *feet in height are very costly, and their increased cost is not justified by increased efficiency.*



2,741 to 2,744.—Installation of forced draft system to old boiler plant. The figures illustrate the simplest method. The fan which is of steel plate with direct connected double cylinder engine, is placed immediately over the end of a brick duct into which the air is discharged. This duct is carried under ground across the front of the boilers, to the ash pits of each of which connection is made through branch ducts. Each branch duct opening is provided with special ash pit damper, operated by notched handle bar, as illustrated in the detail. This method of introduction serves to distribute the air within the ash pit, and to secure even flow through the fuel upon the grate above. Of course, the ash pit doors must remain closed in order to bring about this result. A chimney of sufficient height to merely discharge the gases above objectionable level is all that is absolutely necessary with this arrangement. Although the introduction of a fan in an old plant is usually evidence of the insufficiency of the existing chimney to meet the requirements, such a chimney, will, however, usually serve as a discharge pipe for the gases when the fan is employed. The fan thus becomes more than a mere auxiliary to the chimney; it practically supplants it so far as the method of draught production is concerned.

The latest chimney practice is to build two or more small chimneys instead of one large one. A notable example is the Spreckels Sugar Refinery in Philadelphia, where three separate chimneys are used for one boiler plant of 7,500 horse power. The three chimneys are said to have cost several thousand dollars less than an equivalent single chimney.

Very tall chimneys have been characterized by one writer as "*mon-uments to the folly of their builders.*"


CHIMNEY
ECONOMIZERS
DAMPERS
BY-PASS
BY-PASS
BOILERS
DAMPERS
BOILERS
FLUE
BOILERS
BOILERS
FLUE
BOILERS
BOILERS
ECONOMIZERS
FANS
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FLUE
BOILERS
BOILERS
BOILERS
BOILERS

FIGS. 2,745 and 2,746.—Comparison of chimney draft and mechanical draft. The illus-tions show a plant of 2,400 H. P. of modern water tube boilers, 12 in number, set in pairs and equipped with economizers. Fig. 2,745 indicates the location of a chimney, 9 feet in internal diameter by 180 feet high, designed to furnish the necessary draft; fig. 2,746 represents the same plant with a complete duplex induced draught apparatus substituted for the chimney, and placed above the economizer connections. Each of the two fans is driven by a special engine, direct connected to the fan shaft, and each is capable of pro-ducing draft for the entire plant. A short steel plate stack unites the two fan outlets and discharges the gases just above the boiler house roof. All of the room necessary for the chimney is saved, and no valuable space is required for the fans.

Ques. How is mechanical draft secured?

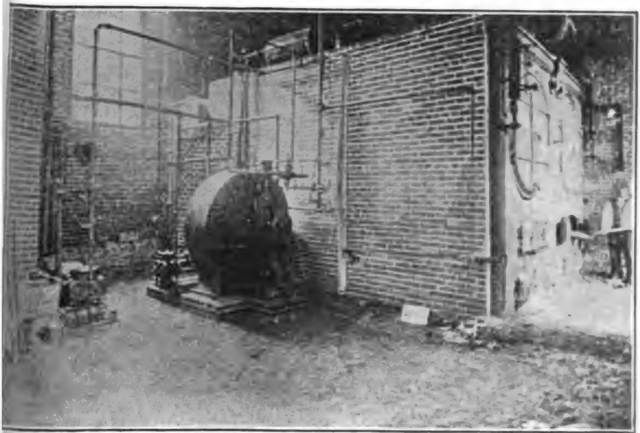
Ans. In two ways, known respectively as *induced draught* and *forced draught.*

Ques. Describe the method of induced draft.

Ans. A fan is located in the smoke flue, and which in operation draws the gases through the furnace and discharges them into a *short* chimney.

Ques. Describe the method of forced draft.

Ans. In this method, air is forced into the furnace underneath the grate bars by means of a fan or a steam jet blower.



2747.—Forced draft plant with hollow bridge wall at the Crystal Water Co., Buffalo N. Y. The air is delivered to the ash pit via the hollow bridge wall, being supplied under pressure by the blower seen at the side of the boiler setting. As shown, the blower is operated by a small reciprocating engine; however, compact blowing units with steam turbine drive can be had and which are designed to be placed in the boiler setting.

Ques. What is the application of the two systems?

Ans. Induced draft is installed mostly in new plants, while rced draft is better adapted to old plants.

Steam Turbines.—It is not the author's intention to discuss length the steam end of the electric plant, because too much ace would be required, and also because the subject belongs operly to the field of mechanical engineering rather than

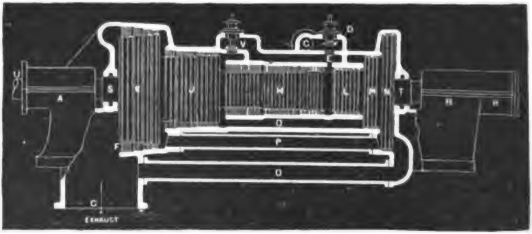


FIG. 2,748.—Longitudinal section of elementary Parsons type steam turbine. The turbine consists essentially of a fixed casing, or cylinder, and a revolving spindle or drum. The ends of the spindle are extended in the form of a shaft, carried in two bearings A and B. and, excepting the small parts of the governing mechanism and the oil pump, these bearings are the only rubbing parts in the entire turbine. Steam enters from the steam pipe at C and passes through the main throttle or regulating valve D, which, as actually constructed, is a balanced valve. This valve is operated by the governor through suitable controlling mechanism. The steam enters the cylinder through the passage E and, turning to the left passes through alternate stationary and revolving rows of blades, finally emerging from them at F and flowing through the connection G to the condenser or to the atmosphere, depending upon whether the turbine is condensing or non-condensing. Each row of blades, both stationary and revolving, extends completely around the turbine and the steam flows through the full annulus between the spindle and the cylinder. In an ideal turbine the lengths of the blades and the diameter of the spindle which carries them would continuously and gradually increase from the steam inlet to the exhaust. Practically, however, the desired effect is produced by making the spindle in steps, there being generally three such steps or stages, H, J and K. The blades in each step are arranged in groups of increasing length. At the beginning of each of the larger steps, the blades are usually shorter than at the end of the preceding smaller step, the change being made in such a way that the correct relation of blade length to spindle diameter is secured. The steam, acting as previously described, produces a thrust tending to force the spindle toward the left, as seen in the cut. This thrust, however, is counteracted by the "balance pistons," L, M and N, which are of the necessary diameter to neutralize the thrust on the spindle steps, H, J and K, respectively. These elements are called "pistons" for convenience, although they do not come in contact with the cylinder, but both the pistons and the cylinder are provided with alternate rings which form a labyrinth packing to retard the leakage of steam. In order that each balance piston may have the proper pressure on both sides, equalizing passages O, P and Q are provided connecting the balance pistons with the corresponding stages of the blading: The end thrust being thus practically neutralized by means of the balance pistons, the spindle "floats" so that it can be easily moved in one direction or the other. In order to definitely fix the position of the spindle, a small adjustable collar bearing is provided at R, inside the housing of the main bearing B. This collar bearing is adjustable so as to locate and hold the spindle in such position as that there will be such a clearance between the rings of the balance piston and those of the cylinder, that the leakage of steam will be reduced to a minimum and, at the same time, prevent actual contact under varying conditions of temperature. Where the shaft passes out of the cylinder, at S and T, it is necessary to provide against in-leakage of air or out-leakage of steam by means of glands. These glands are made tight by water packing without metallic contact. The shaft of the turbine is extended at U and coupled to the shaft of the alternator by means of a flexible coupling. The high pressure turbines are so proportioned that, when using steam as previously described, they have enough capacity to take care of the ordinary fluctuations of load when controlled by the governor through the valve D, thus insuring maximum economy of steam consumption at approximately the rated load. To provide for overloads, the valve V is supplied to admit steam to an intermediate stage of the turbine. This valve shown diagrammatically in the illustration, is arranged to be operated by the governor and is, according to circumstances, located either as shown by the illustration, or at another stage of the turbine.

electrical engineering. However, because of the recent introduction of the steam turbine for the direct driving of large generators, and the fact that it is now almost universally used in large central stations, a detailed explanation of its principles and construction may not be out of place.

A turbine is a machine in which a rotary motion is obtained by transference of the *momentum* of a fluid or gas. In general the fluid is guided by fixed blades, attached to a casing, and, impinging on other blades mounted on a drum or shaft, causing the latter to revolve.

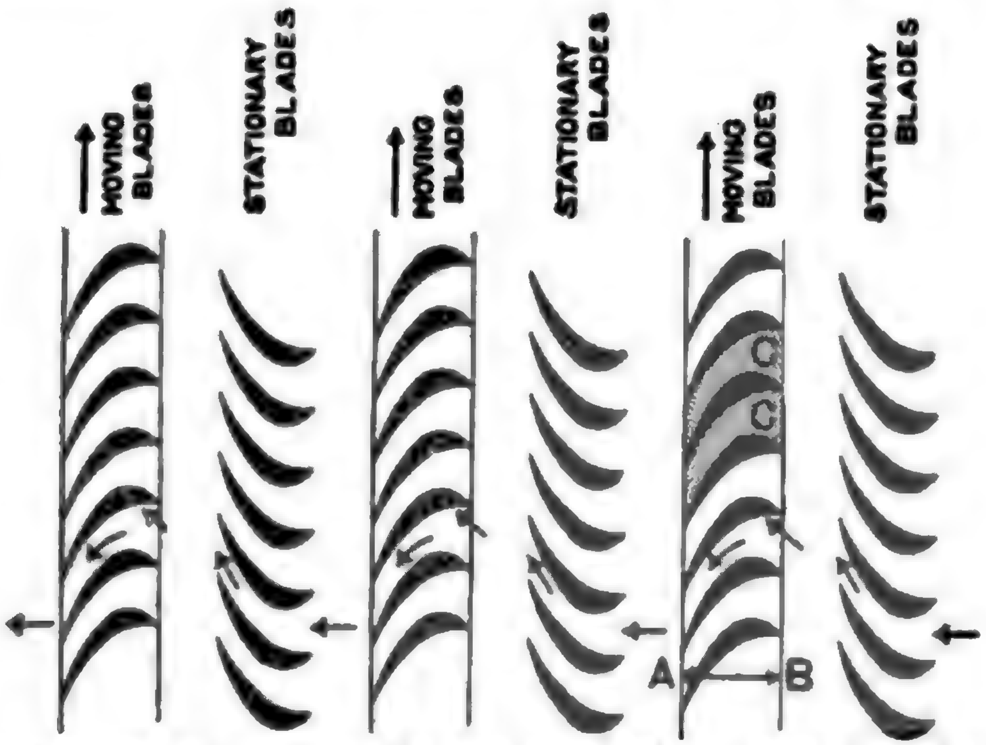


Fig. 2,749.—Arrangement of blading in Parsons type turbine, consisting of alternate moving and stationary blades. The path taken by the steam is indicated by the arrows.

Turbines are classed in various ways as: 1, *radial flow*, when the steam enters near the center and escapes toward the circumference; and 2, *parallel flow*, when the steam travels *axially* or parallel to the length of the turning body.

Turbines are commonly, yet erroneously classed as:

1. Impulse;
2. Reaction.

Ques. What is the distinction between these two types?

Ans. In the so called impulse type, *steam enters and leaves the passages between the vanes at the same pressure.* In the so called reaction type, *the pressure is less on the exit side of the vanes than on the entrance side.*

Fig. 2,750 is a sectional view of the Parsons-Westinghouse parallel flow turbine. Steam from the boiler enters first a receiver in which are the governor controlled admission valves. These valves are actuated by a centrifugal governor.

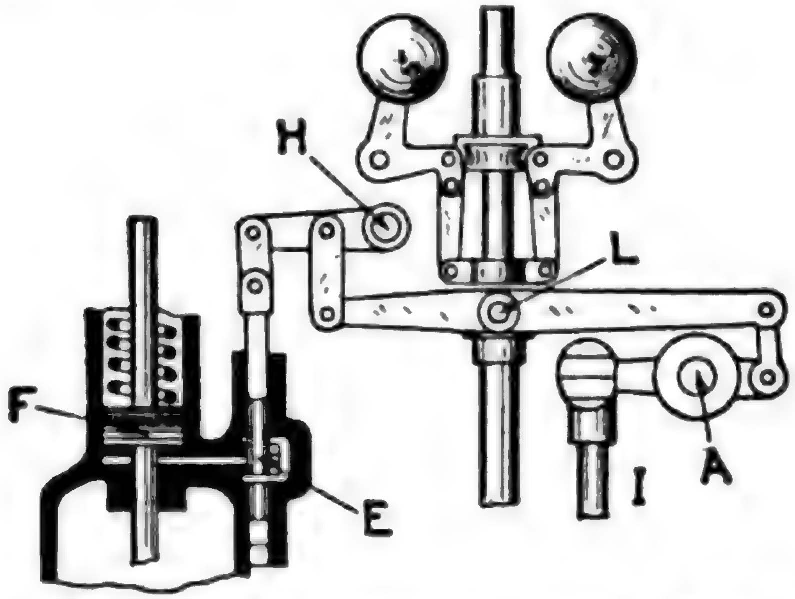


FIG. 2,750.—Sectional view of Parsons-Westinghouse turbine, showing rotor and governor.

Steam does not enter the turbine in a continuous blast, but intermittently, or in puffs. The speed regulation is therefore accomplished by proportioning the duration of these puffs to the load of the engine, this being effected by the governor, fig. 2,752.

The governor of the turbine has only to move a small pilot valve or slide, E, which admits steam under the piston F, and lifts the throttle valve proper off its seat.

As soon as the pilot valve closes, the spring shifts the main throttle valve. Thus, at light loads, the main throttle or admission valve is continually opening and shutting at uniform intervals, the length of time during which it remains open depending upon the load.

As the load increases, the duration of the valve opening also increases until at full load the valve does not reach its seat at all and the steam flows steadily through the turbine. The steam thus admitted flow into the annular passage A, fig. 2,750, by the opening S, and then pas the blades, revolving the rotor.

When the load increases above the normal rated amount a secondary pilot valve is moved by the same means, this in turn admitting steam to a piston, similar to F, which lifts another throttle valve. This admits steam into the annular space I, so that it acts upon the larger diameter of the drum or rotor, giving largely increased power for the time being.

The levers or arms of the governor are mounted upon knife edges instead of pins, making it extremely sensitive. The tension spring may be adjusted by hand while the turbine is running.

The governor does not actually move the pilot valve, but shifts the point L in fig. 2,752. A reciprocating motion is given to the rod I by a small eccentric on the governor shaft; this is driven by worm gearing shown near O in fig. 2,750, so that the eccentric makes one revolution to about eight of the turbine. Thus, with a turbine running 1,200 revolutions, the rod I would be moved up and down 150 times per minute. As the points A and H are fixed, the motion is conveyed to the small pilot valve E, thus giving 150 puffs a minute. The governor in shifting the point L brings the edge of the pilot valve nearer the port and so cuts off the steam earlier.

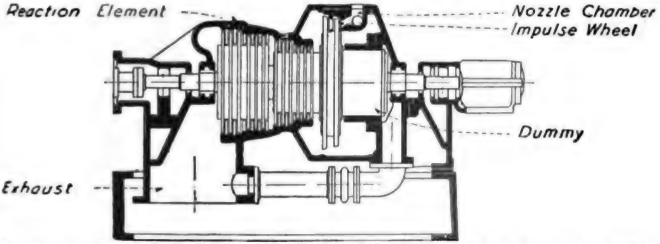


FIG. 2,751.—Sectional view of a combination impulse and reaction single flow turbine. This is a modification of the single flow type, in which the smallest barrel of reaction blading is replaced by an impulse wheel. Steam is admitted to the nozzle block A, is expanded in the nozzles and discharged against a portion of the periphery of the impulse wheel. The intermediate and low pressure stages are identical with the corresponding stages in the single flow type. The substitution of the impulse element for the high pressure section of reaction blading has no influence one way or another on the efficiency. That is to say the efficiency of an impulse wheel is about the same at the least efficient section of reaction blading. This design is attractive, however, in that it shortens the machine materially, and gives a stiffer design of rotor. The entering steam is confined in the nozzle chamber until its pressure and temperature have been materially reduced by expanding through the nozzles. As the nozzle chamber is cast separately from the main cylinder, the temperature and pressure differences to which the cylinder is subjected are correspondingly lessened. However, probably on account of its small diameter at the high pressure section, the straight Parsons type has always shown itself to be adequate for all of the steam pressures and temperatures encountered in ordinary practice.

The annular diameter or space between the rotor and the stator is gradually increased from inlet to exhaust, the blades being made longer in each ring. When the mechanical limit is reached, the diameter of the rotor is increased as at I and D so as to keep the length of blade within bound.

Balance pistons as at B, C, F are attached to the rotor, their office being to oppose end thrust upon those blades in corresponding diameter of the rotor. Communication is established through the passage V and pipe M between the eduction pipe and the back of these pistons, thus increasing the efficiency of their balancing and also taking care of any leakage past them.

A small thrust bearing T prevents end play of the rotor, and is adjustable to maintain the proper clearance between the rings of blades; this varies from ⅛ inch at the admission to 1 inch at the exhaust. This bearing also takes up any extra unbalanced thrust. A turbine should operate with a high vacuum, because without this it does not compare favorably with an ordinary reciprocating engine from the point of economy.

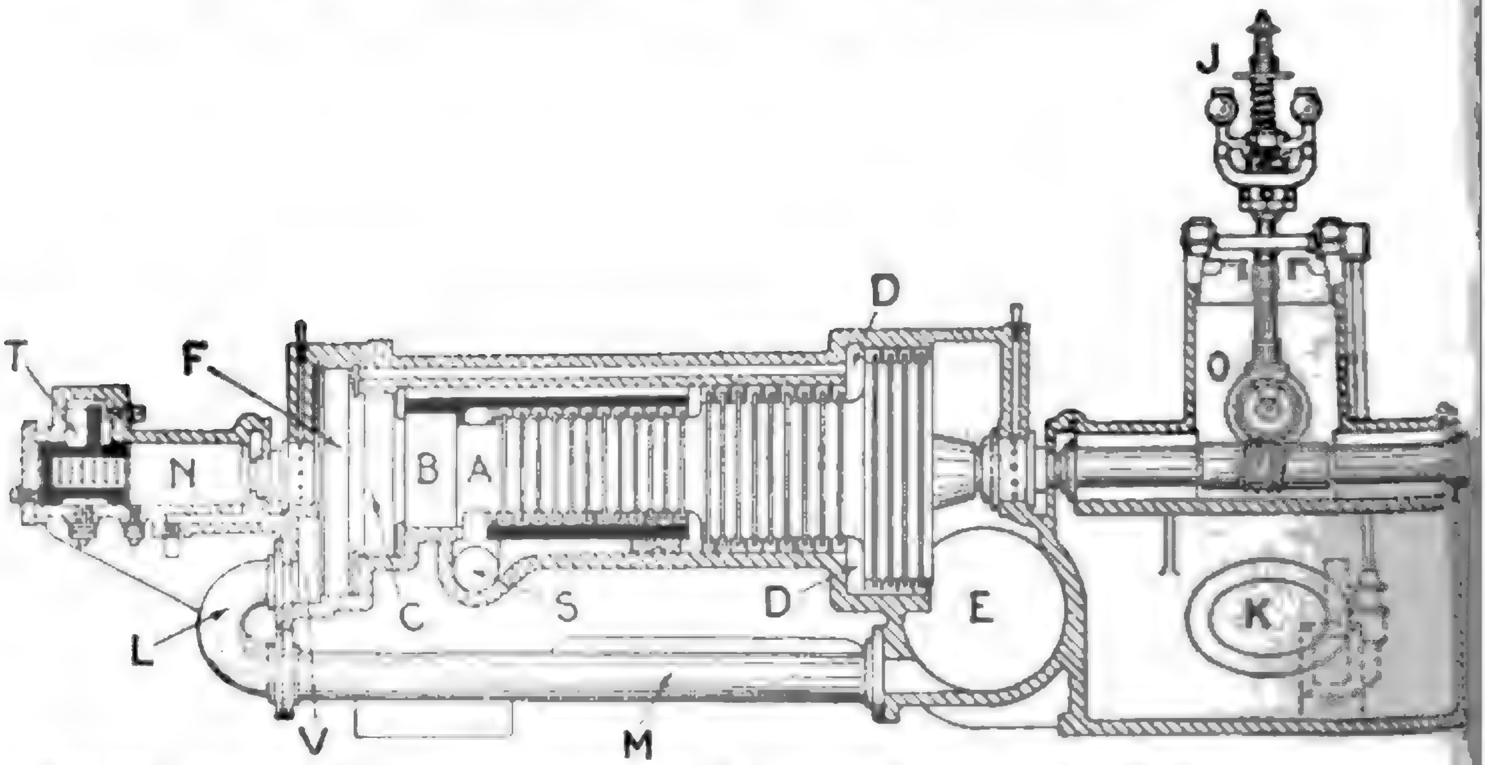


FIG. 2,752.—Sectional view of governor of the Parsons-Westinghouse turbine.

Separate air pumps are provided to create the vacuum.

Where the ordinary type of vertical air pump is employed, a booster or *vacuum increaser* is added, as nothing below 26 inches is advisable 28 and 29 inches being always striven for. It is also preferable to use a certain amount of *superheat* with steam turbines.

To assist in producing the high vacuum, exhaust passages are made large, the eduction passage E in fig. 2,750 being nearly twenty-three times the area of the steam pipe.

Among other details, a noteworthy feature is a small oil pump K which circulates oil through bearings of the machinery, the oil being drawn from the tank under the governor shaft and gravitating there after use. No pressure of oil is employed. Stuffing rings prevent leakage; these consist of alternate grooves and collars in shaft and bearing, like the grooves in an indicator piston.

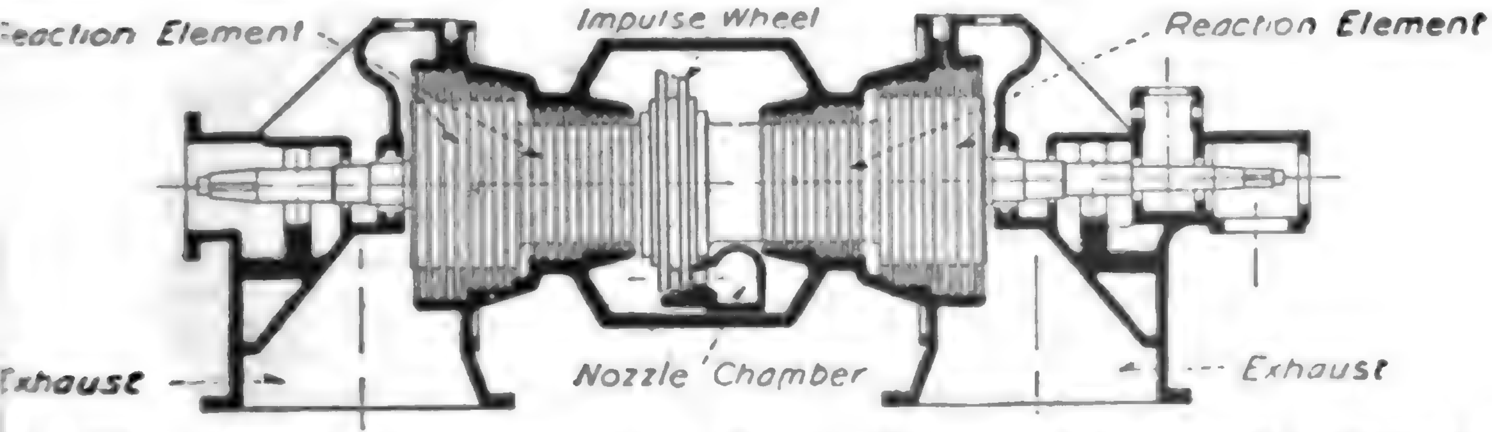
Digitize

Ques. Why is a high vacuum desirable?

Ans. Because the turbine is capable of expanding the steam to a very low terminal pressure, and this is necessary for economy.

Ques. What may be said of the working pressures for turbines?

Ans. To meet the varied conditions of service, turbines are designed to operate with: 1, high pressure, 2, low pressure, or 3, mixed pressure.



ig. 2,753.—Sectional view of a double flow turbine. The maximum economical capacity of a single flow turbine is limited by the rotative speed. The economical velocity at which the steam may pass through the blades of the turbine depends on the velocity of the moving blades. The capacity of the turbine depends on the weight of the steam passed per unit of time, which in turn depends on the mean velocity and the height of the blades. For a given rotative speed, the mean diameter of blade ring practicable is limited by the allowable stresses due to centrifugal force, and there is a practical limit for the height of the blades. Now if the rotative speed be taken only half as great, the maximum diameter of the rotor may be doubled and, without increasing the height of the blades, the capacity of the turbine will be doubled. So with the single flow steam turbine as well as with the single crank reciprocating engine, there is a practical limiting economical capacity for any given speed. If this limit be reached with a single crank reciprocating engine, a unit of double the power may be produced at the same speed by coupling two single crank engines to one shaft. Similar results are secured making a double flow turbine which is in effect, as will be seen from the figure, two single flow turbines made up in a single rotor in a single casing with a common inlet and two exhaust. Steam enters the nozzle block, acts on the impulse element, and then the current divides, one-half of the steam going through the reaction blading at the left of the impulse wheel; the remainder passes over the top of the impulse wheel and through the impulse blading at the right.

High pressure turbines operate at about the same initial pressure as triple expansion engines.

Low pressure, as here applied, means the exhaust pressure of the reciprocating engine from which the exhaust steam passes through the turbine before entering the condenser.

Mixed pressure implies that the exhaust steam is supplemented, for heavy loads, by the admission of live steam.

Ques. What determines the working pressure?

Ans. When all the power is furnished by the turbine, it is designed for high pressure; when operated in combination with

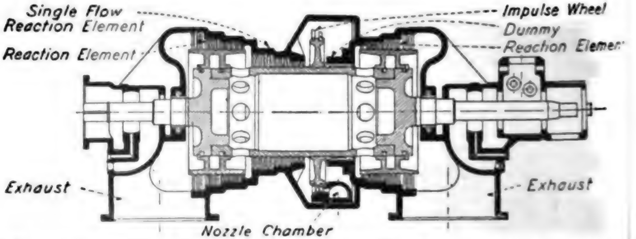


FIG. 2,754.—Sectional view of a semi-double flow turbine. This is a modification in which th intermediate section of reaction blading is single flow, and the low pressure section only double flow. This would be analogous to a four cylinder triple expansion engine, that one with one high pressure, one intermediate pressure and two low pressure cylinders— a design not at all uncommon in very large engines in which the required dimensions of single low pressure cylinder would be prohibitive. Such turbines are useful for capaci greater than is desirable for a single flow turbine, and which are still below the maxim possibilities of a double flow turbine of the same speed. In such machines the best efficienc is secured by making the intermediate blading in a single section large enough to pass th entire quantity of steam. A "dummy" similar to those used on the single flow Pars type, shown at the right of the impulse wheel, compels all of the steam to pass through th single intermediate section of the reaction blading, and balances the end thrust due t this section. When the steam issues from the intermediate section, the current is divid one-half passing directly to the adjacent low pressure section, while the other half pass through the holes shown in the periphery of the hollow rotor and through the rotor it beyond the dummy ring, into the other low pressure section at the left hand end of th turbine.

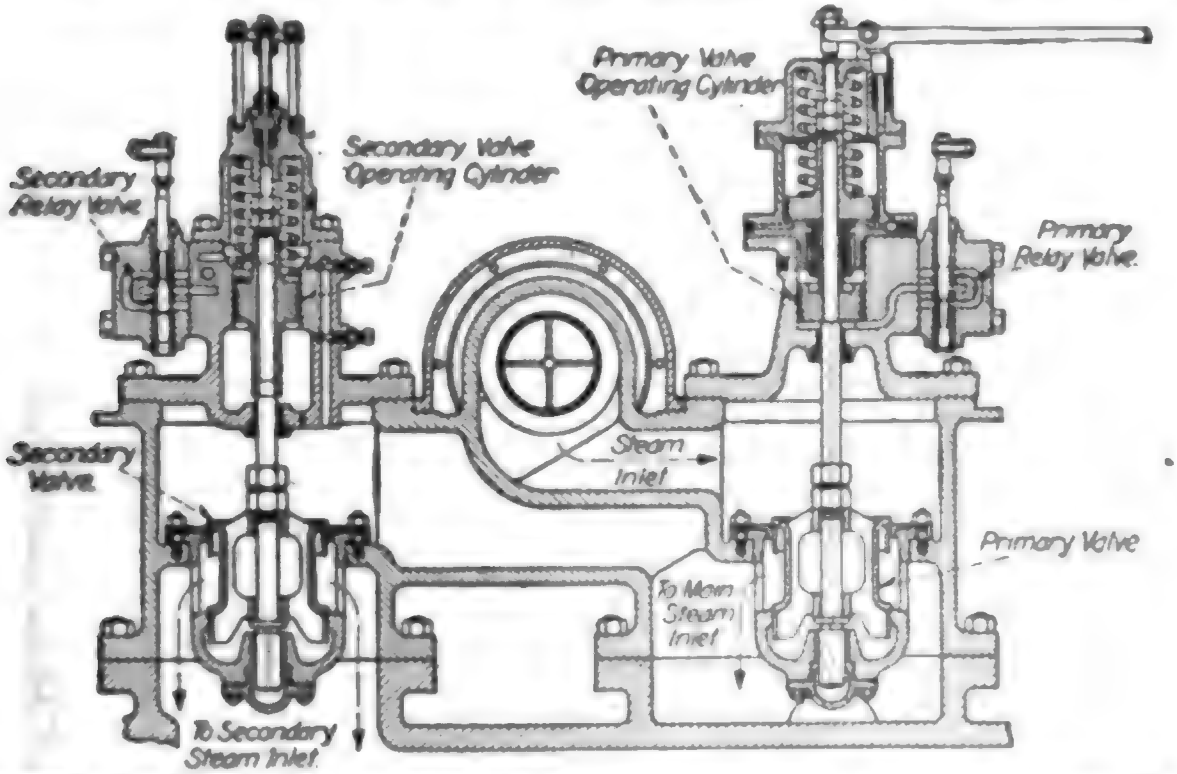
NOTE.—There are logical engineering reasons for the existence of the several types turbine, viz., single flow, double flow, and semi-double flow. The double flow turbine is inherently superior to the single flow design, but is used under conditions for which the s flow machine is unsuitable. Similarly, the semi-double flow is recommended only for conditi which it can meet more satisfactorily than either of the other types.

NOTE.—Low pressure turbines use exhaust steam from non-condensing engines and valuable as an adjunct to existing plants for the purpose of increasing economy and capa with a minimum outlay for new equipment.

NOTE.—Bleeder turbines are for use in plants which are required to furnish, not on power, but also considerable and varying quantities of low pressure steam for heating purpo In these turbines a part of the steam after it has done work in the high pressure stages may diverted to the heating system, and the remainder expanded through the low pressure bla and exhausted into the condenser. In this way none of the energy of the heating steam, due the difference of pressure between the boiler and the heating system is wasted. On the oth hand if no steam is required for heating purposes, the turbine operates just as efficiently ough the bleeder feature were absent.

reciprocating engine, low pressure is used for constant load, nd mixed pressure for variable load.

The De Laval steam turbine is termed by its builders a high speed rotary steam engine. It has but a single wheel, fitted with vanes or buckets of such curvature as has been found to be best adapted for receiving the impulse of the steam jet. There are no stationary or guide blades, the angular position of the nozzles giving direction to the jet. The nozzles are placed at an angle of 20 degrees to the plane of motion of the buckets. The best energy in the steam is practically devoted to the production of velocity in the expanding or divergent nozzle, and the velocity thus attained by the issuing jet of steam is about 4,000 feet per second. To attain the maximum efficiency, the buckets attached to the periphery of the wheel against which this jet impinges should have a speed of about 1,900 feet per second, but, owing to the difficulty of producing a material for the wheel strong enough to withstand the strains induced by such a high speed, it has been found necessary to limit the peripheral speed to 1,200 or 1,300 feet per second.

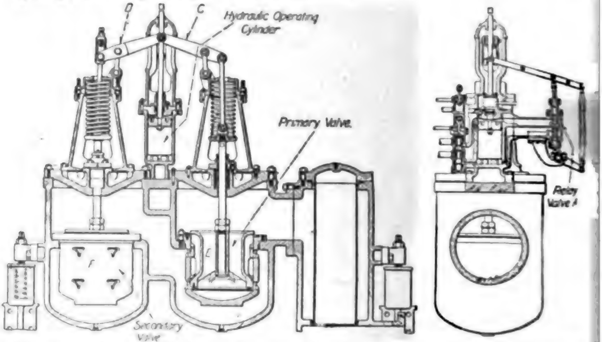


2,755.—Westinghouse valve gear with steam relay. In the smaller turbines, the governor acts directly on the steam admission valves, opening first the primary valve, and then, if necessary, the secondary valve, after the primary is fully open. In turbines of the single flow Parsons type, the governor actuates two small valves controlling ports leading to steam relay cylinders which operate the admission valves. The little valve controlling the relay cylinder for the secondary valve has more lap than the other and consequently does not come into action until the primary valve has attained its maximum effective opening. The figure shows the general design of this type of valve gear.

It is well known that in a correctly designed nozzle the adiabatic expansion of the steam from maximum to minimum pressure will convert the entire static energy of the steam into kinetic energy. Theoretically this is what occurs in the De Laval nozzle. The expanding steam acquires great velocity, and the energy of the jet of steam issui from the nozzle is equal to the amount of energy that would be develope if an equal volume of steam were allowed to adiabatically expand be hind the piston of a reciprocating engine, a condition, however, which for obvious reasons has never yet been attained in practice with the reciproca ing engine. But with the divergent nozzle the conditions are different.

The Curtis turbine is built by the General Electric Company at the works in Schenectady, N. Y., and Lynn, Mass. They are of the hor zontal and vertical types. In the vertical type the revolving parts are se upon a vertical shaft, the diameter of the shaft corresponding to the si of the machine.

The shaft is supported by and runs upon a step bearing at the botto This step bearing consists of two cylindrical cast iron plates beari upon each other and having a central recess between them into whi lubricating oil is forced under pressure by a steam or electrically drive pump, the oil passing up from beneath.



FIGS. 2,756 and 2,757.—Westinghouse valve gear with oil relay. Governors for the larger turbi particularly those of the combination impulse and reaction double, or single double f type, employ an oil relay mechanism, as shown in the figure, for operating the steam val In these turbines the lubricating oil circulating pump, maintains a higher pressure th is required for the lubricating system. The governor controls a small relay valve A wh admits pressure oil to, or exhausts it from the operating cylinder. When oil is admi to the operating cylinder raising the piston, the lever C lifts the primary valve E. T lever D moves simultaneously with C, but on account of the slotted connection with t stem of the secondary valve F, the latter does not begin to lift until the primary valve raised to the point at which its effective opening ceases to be increased by further upw travel. In the Westinghouse designs, the operating valve, A is connected not only t the governor, but also to a vibrator, which gives it a slight but continuous reciprocat motion, while the governor controls its mean position. The effect of this is manifested a slight pulsation throughout the entire relay system, which, so to speak, keeps it "ali and ready to respond instantly to the smallest change in the position of the govern The oil relay can be made sufficiently powerful to operate valves of any size, and it is a in effect a safety device in that any failure of the lubricating oil supply will automatica d immediately shut off the steam and stop the turbine.

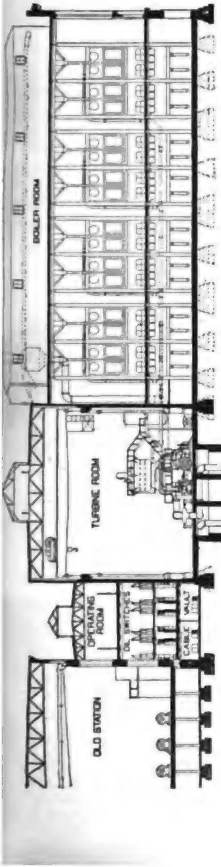


FIG. 2,715.—Elevation of new turbine central station erected by the Boston Edison Co. The turbine room is 68 feet, 4 inches wide and 630 feet long from outside to outside of the walls. The boiler room is 149 feet, 6 inches by 640 feet and equipped with twelve groups of boiler, one group consisting of eight 512 H.P. boilers for each turbine. The switching arrangements are located in a separate building as shown in the elevation. The total floor space covered by boiler room, turbine room and switchboard room is 2.04 square feet per k.w. The boilers are all on the ground floor. See fig. 2,714 for plan.

A weighted accumulator is sometimes installed in connection with the oil pipe as a convenient device for governing the step bearing pumps, and also as a safety device in case the pumps should fail, but it is seldom required for the latter purpose, as the step bearing pumps have proven after a long service in a number of cases, to be reliable. The vertical shaft is also held in place and kept steady by three sleeve bearings one just above the step, one between the turbine and generator, and the other near the top.

These guide bearings are lubricated by a standard gravity feed system. It is apparent that the amount of friction in the machine is very small, and as there is no end thrust caused by the action of the steam, the relation between the revolving and stationary blades may be maintained accurately. As a consequence, therefore, the clearances are reduced to the minimum.

The Curtis turbine is divided into two or more stages, and each stage has one, two or more sets of revolving blades bolted upon the peripheries of wheels keyed to the shaft. There are also the corresponding sets of stationary blades bolted to the inner walls of the cylinder or casing.

The governing of speed is accomplished in the first set of nozzles and the control of the admission valves here is effected by means of a centrifugal governor attached to the top end of the shaft. Th governor, by a very slight movement, imparts motion to levers, which in turn work the valve mechanism.

The admission of steam to the nozzles is controlled by piston valve which are actuated by steam from small pilot valves which are in turn under the control of the governor.

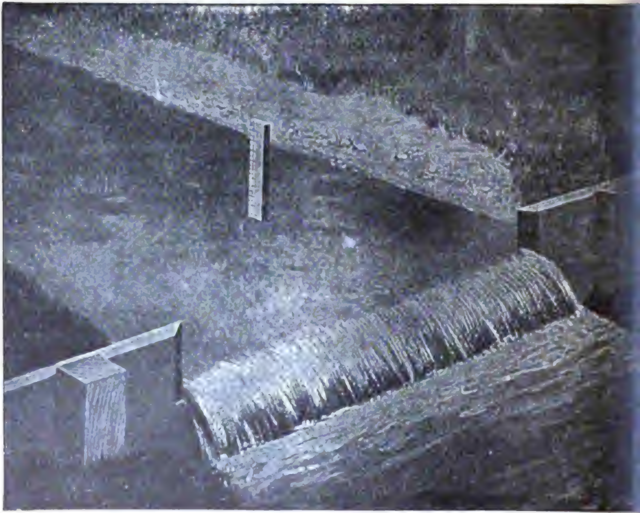


Fig. 2,750.—Illustration of a weir. To make a weir, place a board across the stream at some poi which will allow a pond to form above. The board should have a notch cut in it wi both side edges and the bottom sharply beveled toward the intake, as shown in th above cut. The bottom of the notch, which is called the "crest" of the weir, should b perfectly level and the sides vertical. In the pond back of the weir, at a distance n less than the length of the notch, drive a stake near the bank, with its top precisely lev with the crest. By means of a rule, or a graduated stake as shown, measure the dept of water over the top of stake, making allowance for capillary attraction of the wat against the sides of the weir. For extreme accuracy this depth may be measured t thousandths of a foot by means of a "hook gauge," familiar to all engineers. Havin ascertained the depth of water over the stake, refer to the accompanying table, fr which may be calculated the amount of water flowing over the weir. There are certa proportions which must be observed in the dimensions of this notch. Its length, o width, should be between four and eight times the depth of water flowing over the cre of the weir. The pond back of the weir should be at least fifty per cent. wider than th notch and of sufficient width and depth that the velocity of flow or approach be not ov one foot per second. In order to obtain these results it is advisable to experiment t some extent.

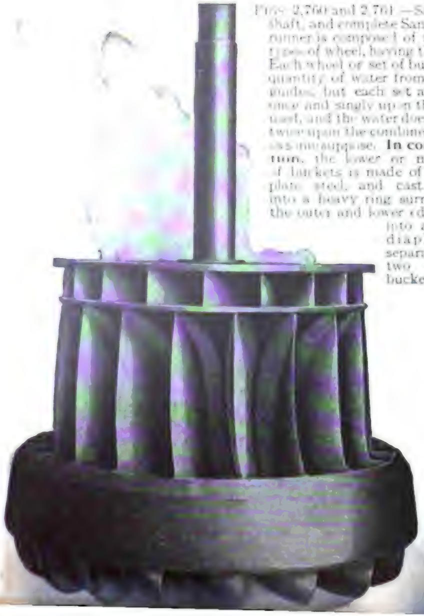
Speed regulation is effected by varying the number of nozzles in flow, that is, for light loads fewer nozzles are open and a smaller volume of steam is admitted to the turbine wheel, but the steam that is admitted impinges against the moving blades with the same velocity always, no matter whether the volume be large or small. With a full load and all the nozzle sections in flow, the steam passes to the wheel in a broad belt and steady flow.

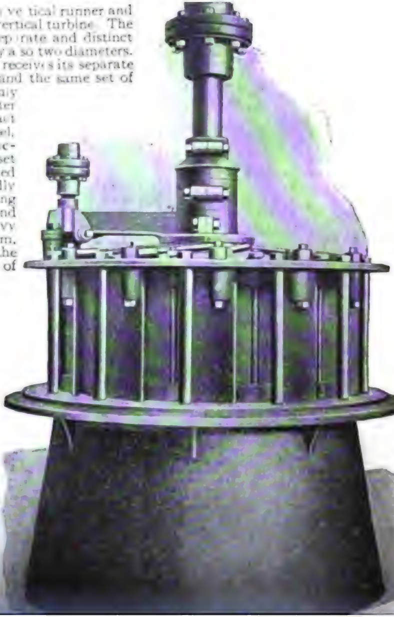
WEIR TABLE

ing cubic feet of water per minute that will flow over a weir one inch wide and from ⅛ to 20⅞ inches deep.

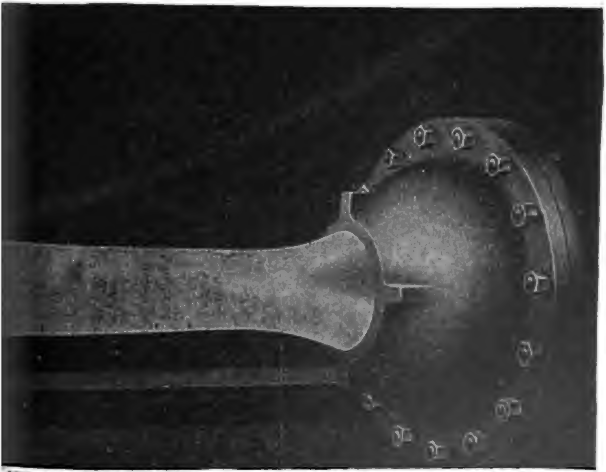
Depth nches		⅛	¼	⅜	½	⅝	¾	⅞
0	.00	.01	.05	.09	.14	.19	.26	.32
1	.40	.47	.55	.64	.73	.82	.92	1.02
2	1.13	1.23	1.35	1.36	1.58	1.70	1.82	1.95
3	2.07	2.21	2.34	2.48	2.61	2.76	2.90	3.05
4	3.20	3.35	3.50	3.66	3.81	3.97	4.14	4.30
5	4.47	4.64	4.81	4.98	5.15	5.33	5.51	5.69
6	5.87	6.06	6.25	6.44	6.62	6.82	7.01	7.21
7	7.40	7.60	7.80	8.01	8.21	8.42	8.63	8.83
8	9.05	9.26	9.47	9.69	9.91	10.13	10.35	10.57
9	10.80	11.02	11.25	11.48	11.71	11.94	12.17	12.41
10	12.64	12.88	13.12	13.36	13.60	13.85	14.09	14.34
11	14.59	14.84	15.09	15.34	15.59	15.85	16.11	16.36
12	16.62	16.88	17.15	17.41	17.67	17.94	18.21	18.47
13	18.74	19.01	19.29	19.56	19.84	20.11	20.39	20.67
14	20.95	21.23	21.51	21.80	22.08	22.37	22.65	22.94
15	23.23	23.52	23.82	24.11	24.40	24.70	25.00	25.30
16	25.60	25.90	26.20	26.50	26.80	27.11	27.42	27.72
17	28.03	28.34	28.65	28.97	29.28	29.59	29.91	30.22
18	30.54	30.86	31.18	31.50	31.82	32.15	32.47	32.80
19	33.12	33.45	33.78	34.11	34.44	34.77	35.10	35.44
20	35.77	36.11	36.45	36.78	37.12	37.46	37.80	38.15

NOTE.—The weir table on this page contains figures 1, 2, 3, etc., in the first vertical mn which indicates the inches depth of water running over weir board notches. Frequently depths measured represent also fractional inches, between 1 and 2, 2 and 3, etc. The horintal line of fraction at the top represents these fractional parts, and can be applied between of the numbers of inches depth, from 1 to 25. The body of the table shows the cubic feet, the fractional parts of a cubic foot, which will pass each minute for each inch in depth, d for each fractional part of an inch by eighths for all depths from 1 to 25 inches. Each of these its is for only one inch width of weir. To estimate for any width of weir the result obtained one inch width must be multiplied by the number of inches constituting the whole horizontal h of weir.





FIGS. 2,760 and 2,761.—Samson vertical runner and shaft, and complete Samson vertical turbine. The runner is composed of two separate and distinct types of wheel, having thereby also two diameters. Each wheel or set of buckets receives its separate quantity of water from one and the same set of guides, but each set acts only once and singly upon the water used, and the water does not act twice upon the combined wheel, as some suppose. **In construction**, the lower or main set of buckets is made of flanged plate steel, and cast solidly into a heavy ring surrounding the outer and lower edges, and into a heavy diaphragm, separating the two sets of buckets.



2,762.—Water discharging from a needle nozzle due to a pressure of 169 lbs. per sq. in.

Hydro-Electric Plants.—The economy with which elec-
ity can be transmitted long distances by high tension alterna-
g currents, has led to the development of a large number of
ter powers in more or less remote regions.

This economy is possible by the facility with which alternating cur can be transformed up and down. Thus at the hydro-electro plant, current generated by the water wheel driven alternator is transfor to very high pressure and transmitted with economy a long distanc the distributing point where it is transformed down to the proper p sure for distribution.

A water wheel or turbine is a machine in which a rotary motio obtained by transference of the momentum of water; broadly speak the fluid is guided by f blades, attached wit casing, and impinging other blades mounted drum or shaft, causin latter to revolve.

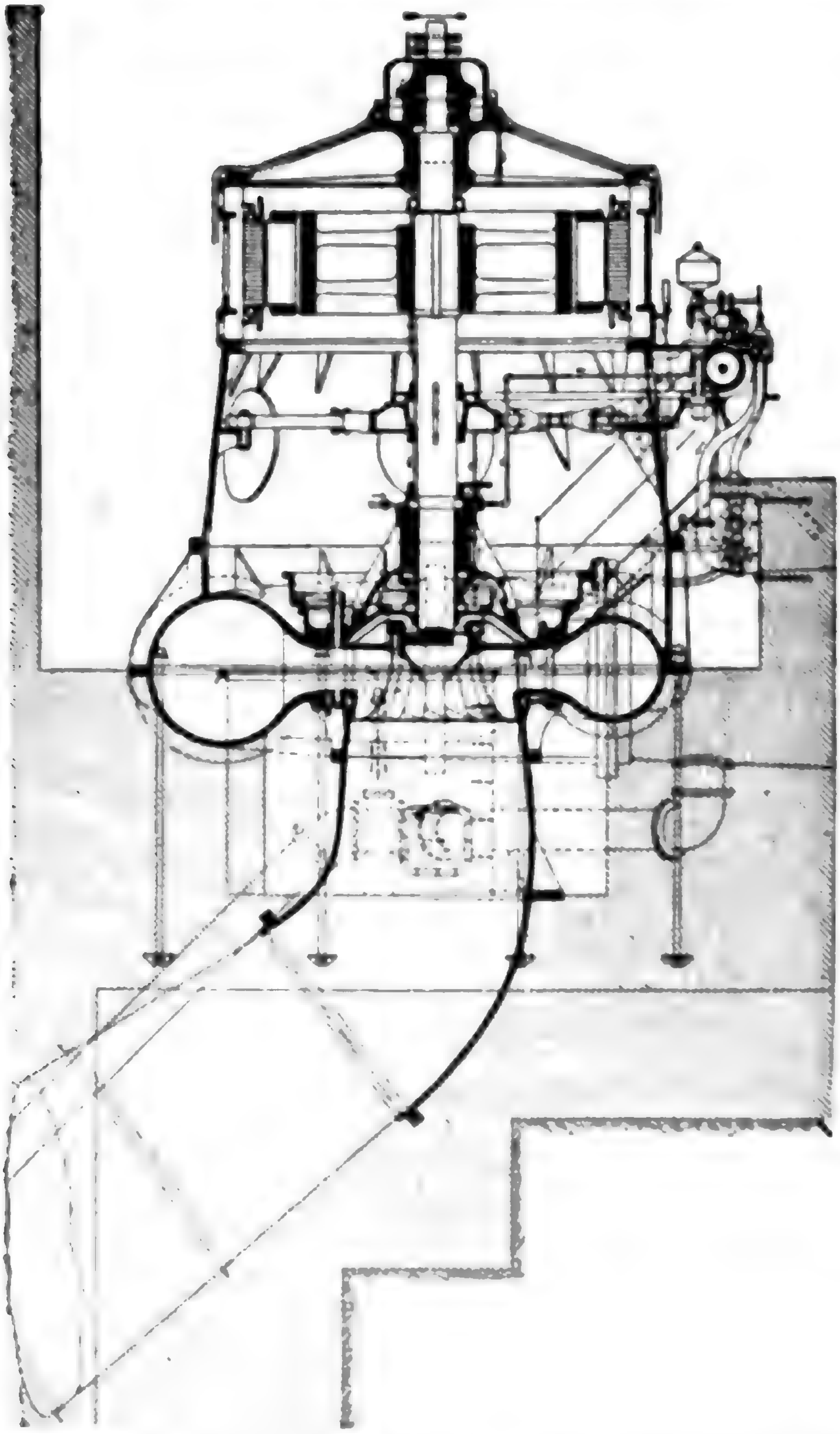


FIG. 2,764.—Sectional elevation of one of the 5,000 horse power vertical Pelton-Francis turbines directly connected to generator, as installed for the Schenectady Power Co.

There are two ge classes of turbine:

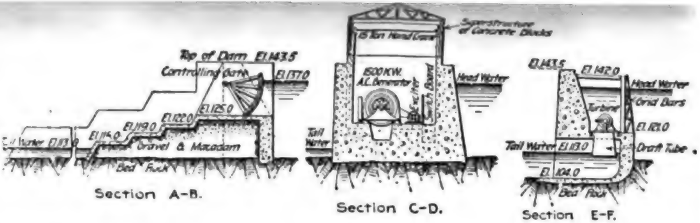
1. Impulse turbines;
2. Reaction turbines.

Ques. What is impulse turbine?

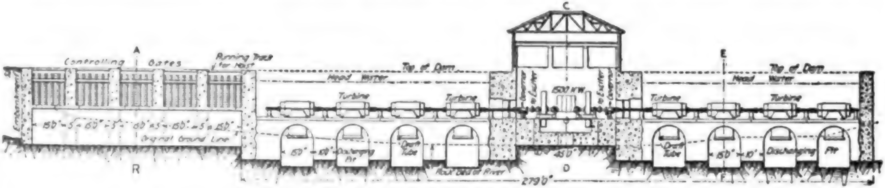
Ans. One in wh the fluid is directed means of a series of n zles against vanes wh it drives.

Ques. What is reaction turbine?

Ans. One in wh the pressure or head the water is emplo rather than its veloc The current is defle upon the wheel by action of suitably posed guide blades,


Top of Dam El.143.5
Controlling Gate
El.137.0
El.125.0
El.122.0
El.119.0
El.116.0
Tail Water El.113.0
Gravel & Macadam
Bed Rock
Section A-B.
15 Ton Hand Crane
Superstructure of Concrete Blocks
1500 K.W. A.C. Generator
Switch Board
Head Water
Tail Water
Section C-D.
El.143.5
El.142.0
Head Water
Grid Bars
Turbine
El.121.0
Tail Water El.113.0
Draft Tube
El.104.0
Bed Rock
Section E-F.

Cross sections of Lowel dam power house, and wheel pits containing sixteen Samson turbines: The section C-D gives an end view of the generator room showing the locations of the generators below the head level water. They are secure against flood water, or leakage, by well constructed stuffing boxes in the iron bulkheads, through which the turbine wheel shafts pass and connect to the generators. Section E-F gives an end view of one of these wheel rooms or penstocks, and shows the extension of the draft tube from wheel case into tail water. The section A-B shows the sub-structure of gravel and macadam under the controlling gates, this forming also a portion or extension of the dam proper. These gates turn on


C
A
Controlling Gates
Running Track for Hoist
Top of Dam
Head Water
Turbine
Embankment
150'-5'-150'-5'-150'-5'-150'-5'-150'
Original Ground Line
Discharging Pit
Draft Tube
1500 KW
Governor
Exciter
E
R
D
F
Rock Bed of River
279'0"

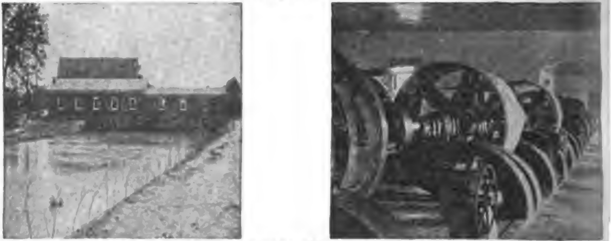
an axis made of two 15 inch I beams securely riveted together with plates and angle irons to which the wooden frame is attached. The radius of the gates is 14 feet. They are designed to allow the water to pass underneath the gate, thus controlling any height of head water. They are intended to take care of an excess of water at unusual stages of the river.

passages being full of water. Rotary motion is obtained by th change in the direction and momentum of the fluid.

Ques. Name three classes of reaction turbines.

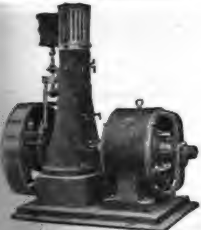
Ans. Parallel flow, inward flow, and outward flow.

Parallel flow turbines have an efficiency of about 70% and are suit for low falls not over 30 feet. Inward and outward flow turbines have efficiency of about 85%. Impulse turbines are suitable for high head



FIGS. 2,769 and 2,770.—Exterior and interior of hydro-electric plant at Harrisburg, Va. It located on the south fork of the Shenandoah River, twelve and one-half miles dista A dam 720 feet long and 15 feet high was built on a limestone ledge running across t river; which with a fall of 5 feet from the dam to the power house, a quarter of a m distant, secured an effective head pressure of 20 feet. The power house, comprising t generator room and the wheel room, also the machinery room, are here shown. The whe room, which is 20 × 40 feet, extends across the head race, and rests upon solid concre walls, forming the sides and ends of the wheel pits. The end wall is 6 feet thick at t bottom, and 4½ feet at the top. It has three arched openings, each 8 feet wide and 9 f high, through which the water escapes after leaving the turbines. The intake is p tected by a wrought iron rack 40 feet long. The power is obtained by three 50 inch verti shaft Samson turbines, with a 20 inch Samson for an exciter. The three large turbi have a rating of 1,350 horse power; and are connected to the main horizontal line shaft bevel mortise gears 7 feet diameter and 15 inches face. The couplings on the main s have 48 inch friction clutch hubs, permitting either or each turbine being operat shut down independently of the others. The main shaft is 85 feet long and 6 inches dia eter; making 280 revolutions. This shaft carries two pulleys 70 inches diameter and inches face for driving the generators. The accompanying illustration shows the har work, gears, pulleys, etc., furnished with the turbines. The 20 inch horizontal Samson turbine of 72 horse power is direct connected to an exciter generator of 25 running 700 rev. per min. The two large generators are driven 450 revolutions per m by belts producing a three phase current of 60 cycles of 11,500 volts for the twelve one-half miles transmission. The line consists of three strands of No. 4 bare copper w This current is used for lighting and power purposes, and the plant is of the latest proved design and construction.

Isolated Plants.—When electric power transmission fr central stations first came into commercial use, the distan from the station at which current could be obtained at a reaso able cost was exceedingly limited.



G. 2,769.—Triumph direct current generator set with upright slide valve engine.

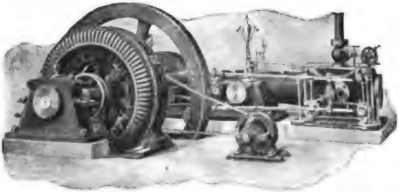
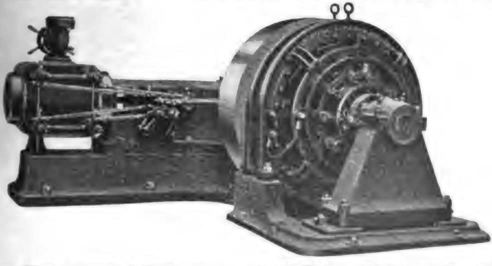


FIG. 2,770.—Murray alternating current direct connected unit with high speed Corliss engine and belt driven exciter. 50, 75 and 100 kva. alternator and 150 R.P.M. engine.



IG. 2,771.—Direct connected direct current unit with Ridgway high speed four valve engine.

IG. 2,772.—Buckeye mobile, or self contained unit consisting of compound condensing engine, boiler, superheater, reheater, feed and air pumps; it produces one horse power on 1½ lbs. of coal, built in sizes from 75 to 600 horse power.

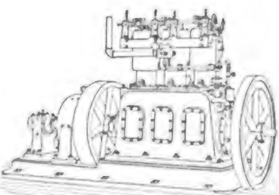


FIG. 2,773.—Westinghouse three cylinder gas engine, direct connected to dynamo, showing application of gas engine drive for small direct conne units.

Consequently, persons desiring electrical power were in the majority of cases forced to install their own apparatus for producing it, this being the origin of isolated plants.

From the nature of the case it is evident that an isolated plant is as a rule smaller and more simple in construction than a central station, and in consequence much more readily operated and managed. It is generally owned by a private individual or a corporation and operated in conjunction with other affairs of a similar character. A basement or other portion of a building is usually set aside in which the necessary apparatus is installed.

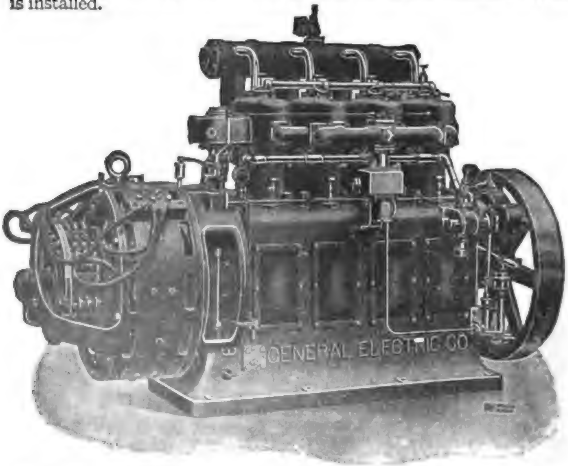
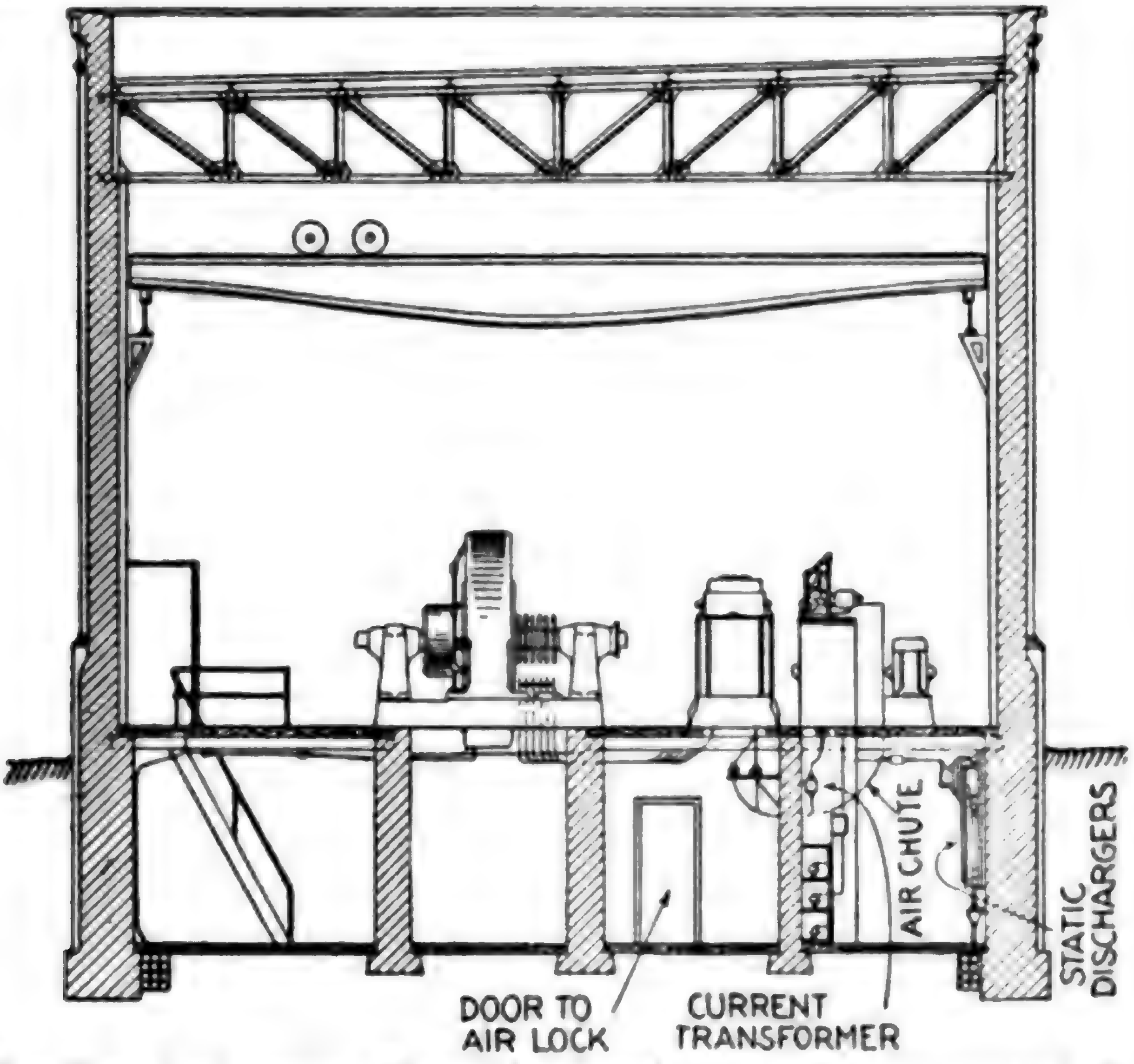


FIG. 2,774.—General Electric 25 kw., gasoline electric generating set for lighting and powe The engine has four cylinders 7¼ × 7½, and runs at a speed of 560 revolutions per minut The total candle power capactiy in Mazda lamps is 20,000. The ignition is by low tensio magneto, coil and battery. Carburetter is of the constant level type to which gasolin is delivered by a pump driven by the engine. Forced lubrication; five crank shaft bearing babbitted; valves in side; overall dimensions 96 × 34 × 60 high; weight 5,000.

Although electricity is now transmitted economically to great distance from central stations, there is still a field for the isolated plant.

The average type of isolated plant has enlarged from a small dynam driven by a little slide valve engine located in an out of the way corne to direct connected generators and engines of hundreds and even thou sands of horse power assembled in a large room specially adapted to th purpose.

In the more modern of these, the electrical outputs are each frequently equal to that of a town central station of respectable size, and the auxiliary equipments are similar in every particular. As a matter of fact, in certain modern isolated plants the only feature that distinguishes them from central stations is that in the former case the owner of the plant represents the sole consumer and conducts other business in connection with it, whereas in the latter case there are a large number of consumers uninterested financially in the enterprise, which is itself generally owned and operated by a company conducting no other business.



ic. 2,775.—Plan of sub-station with air blast transformers and motor operated oil switches and underground 11,000 or 13,200 volt high tension lines.

Sub-Stations.—According to the usual meaning of the erm, a sub-station is a building provided with apparatus for hanging high pressure alternating current received from the entral station into direct current of the requisite pressure, vhich in the case of railways is 550 to 600 volts.

Where traffic is heavy and the railway system of considerable distance, sub-stations are provided at intervals along the line, each receiving high pressure current from one large central station and converting it into moderate pressure direct current for their districts.

Ques. Upon what does the arrangement of the sub-station depend?

Ans. Upon the character of the work and the type of apparatus employed for converting the high pressure alternating current into direct current.

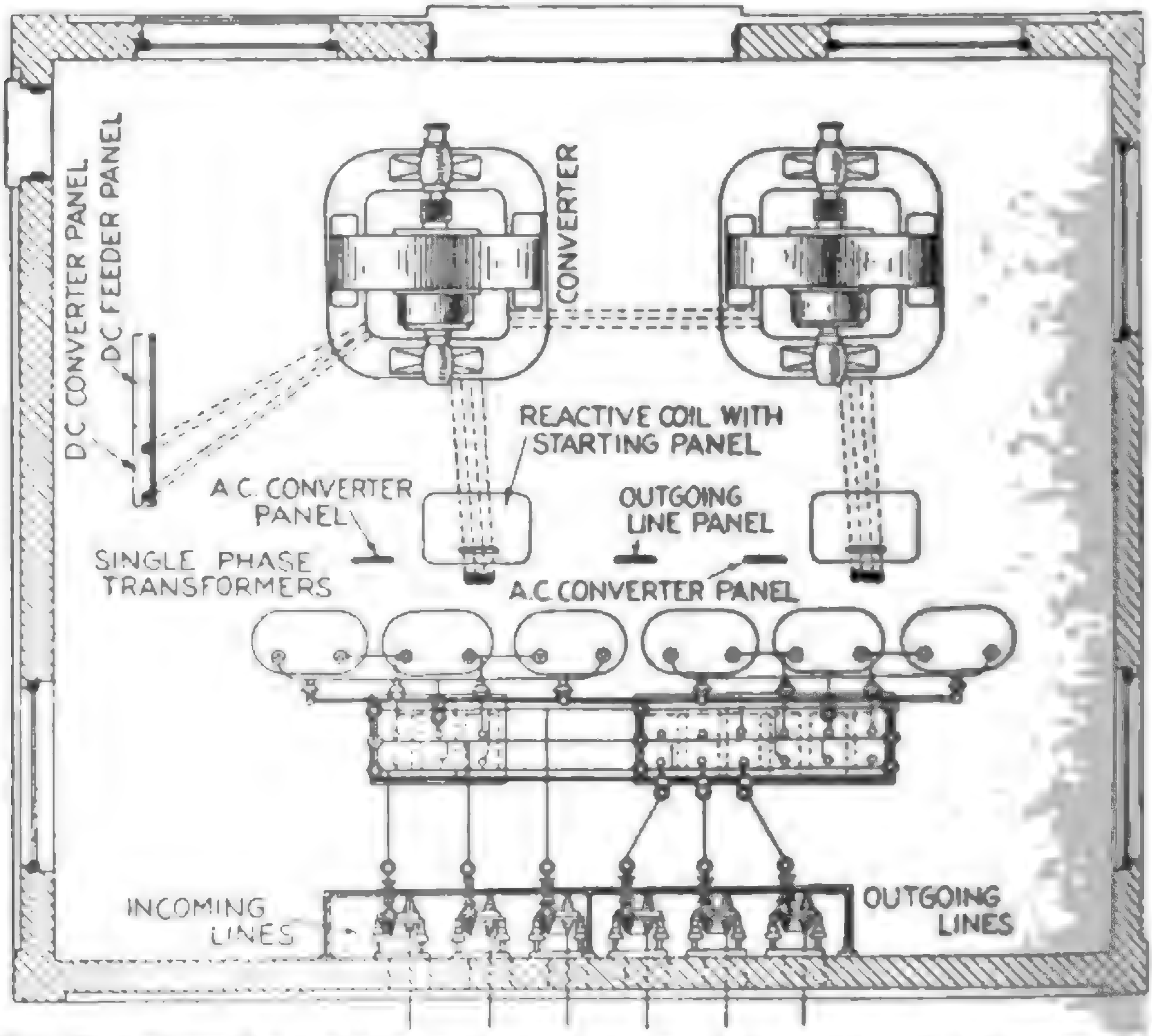

D.C. CONVERTER PANEL
D.C. FEEDER PANEL
CONVERTER
REACTIVE COIL WITH STARTING PANEL
A.C. CONVERTER PANEL
OUTGOING LINE PANEL
SINGLE PHASE TRANSFORMERS
A.C. CONVERTER PANEL
INCOMING LINES
OUTGOING LINES

FIG. 2,776.—Plan of small sub-station with single phase oil insulated self-cooling transf and hand operated oil switches 11,000 or 13,200 volts, overhead high tension lines.

In general it should be substantial, convenient to install or replac the heavy machines, and the layout arranged so that the apparatus ca be readily operated by those in attendance.

An overhead traveling crane is the most convenient method of handling the heavy machinery, and is frequently used in large sub-stations.

Fig. 2,776 shows a sectional view, and fig. 2,777, a plan for a small sub-station containing two rotary converters and two banks of three single phase static transformer operating on a three phase system at 11,000 or 13,200 volts, together with the auxiliary apparatus.

Ques. For three phase installations, what are the merits of separate and combined transformers?

Ans. With separate transformer for each phase, repairs are more readily made in case of accident or burnouts in the coils. The three phase units have the advantage of low first cost.

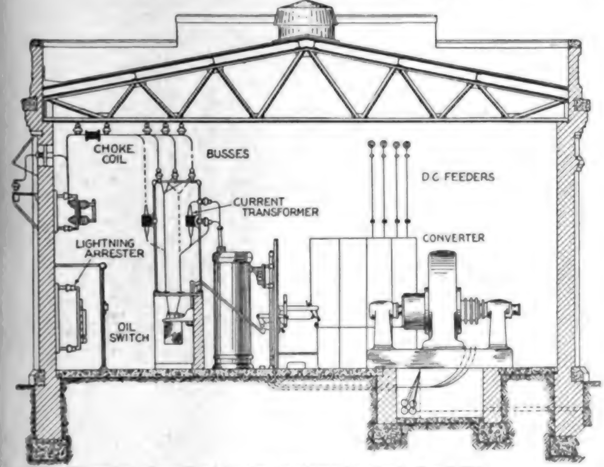


FIG. 2,777.—Elevation of small sub-station, as shown in plan in FIG. 2.776.

Sub-station transformers produce considerable heat, due to the hysteresis and eddy currents, and it is necessary to get rid of it.

Small transformers radiate the heat from the shell and the medium sizes have corrugated shells which increase the surface and provide more rapid radiation.

Large transformers are cooled by an air blast supplied by mot driven blowers or by water pumped through a coil of pipe which immersed in the insulating oil of the transformer. The large size o insulated, water cooled transformers are used on circuits of 33,000 vo or more. In water turbine plants, the water may be piped to the tra former under pressure and the pump omitted which cuts down the co of operating. Air blast transformers usually have a damper or shut for air control.

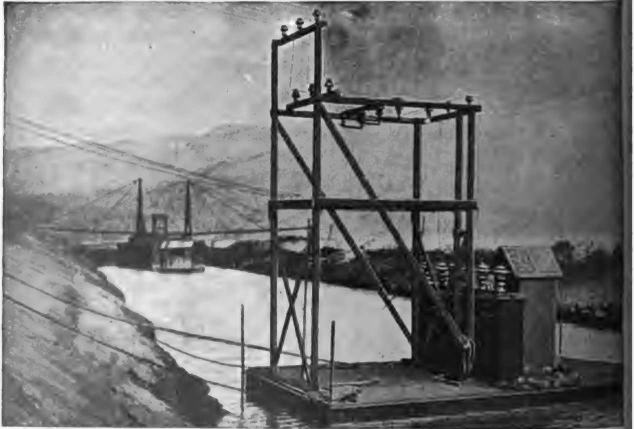


FIG. 2,778.—Marine portable transformer station on Los Angeles Aqueduct. The view sho three 20 kva., Westinghouse out door transformers installed on a float, 33,000 volts h pressure; 440 volts low pressure; 50 cycles.

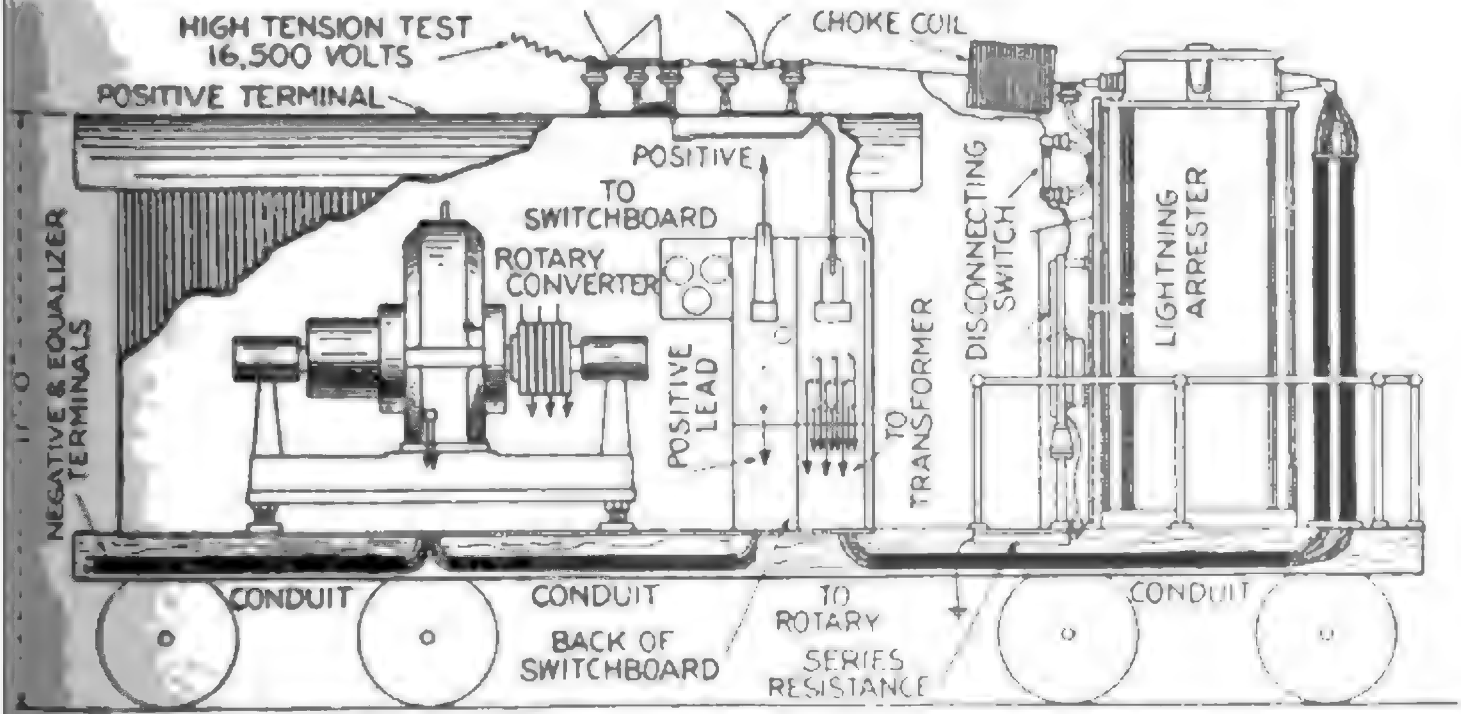
Ques. Explain the use of reactance coils in sub-stations

Ans. In order that the direct current voltage of the ordinar rotary may be regulated by a field rheostat, which calls for a corresponding change in the alternating current voltage, a re- actance coil is provided between the low tension winding and the converter.

Without such a reactance, the maintenance of the same voltage full load as at no load involves excessive leading and lagging curre and consequently excessive heating in the armature inductors, unlesthe resistance drop from the source of constant pressure is small, or the natural reactance of the circuit high.

Ques. What is the effect of weakening the converter field?

Ans. A lagging current is set up which causes a drop in the ractance coil.



IG. 2,779.—Sectional elevation of portable outdoor transformer type sub-station. The high voltage switching and protective apparatus is mounted, out of the way, on the roof of the car, but is operated from the switchboard with a standard remote control handle. The transformer is carried directly over the truck at the uncovered end of the car and the low-tension leads from it run in conduit beneath the floor and up into the cab, (which contains the converter and switchboard) to the converter. The positive lead runs through a conduit and ends in a terminal on the roof. The energy thus makes a complete circuit of the car leaving at a point close to that at which it entered. The low pressure alternating current as well as the direct current positive leads are carried below the car floor in iron conduit supported from the channel frame. The field wires are carried through this conduit to the rheostat. Wiring for the lights is arranged to supply two 5 light clusters. One is fed with the 600 volt direct current and the other with 120 volt alternating current. All lighting conductors are carried in metal moulding carried between the flanges of the channel iron ribs. High wiring is carried entirely on the roof of the car where it is entirely out of the way and where the operator cannot come in contact with it. The switchboard should be of the utmost simplicity. Usually the negative and equalizer switches and the field break-up switch are mounted on the frame of the converter. The double throw switch for starting and running the converter can be mounted under the floor of the car and operated by handle at the switchboard. The rheostat can be mounted back of the switchboard on brackets bolted to the car super-structure. The switchboard need only carry the positive knife switch and circuit breaker, and the alternating current ammeter, voltmeter and power factor meter. Sometimes a watthour meter is added. The positive lead is brought out through a conduit on the roof of the car and is arranged for fastening to the positive feeder. The negative and equalizer terminals are located at the rear end of the car and are arranged so that connection can be easily made from them to the ground and, if necessary, to an equalizer circuit. There is usually a sliding door at each end of the cab and two windows on each side. Above the doors, transoms, extending the width of the cab, are arranged to drop so that a current of air will circulate through the cab under the roof, carrying out the heated air. There are also several ventilating holes beneath the converter in the floor of the car. These provisions insure a constant circulation of air through the car which carries away all heated air.

Ques. State the effect of strengthening converter field.

Ans. A leading current is set up which gives a rise of voltage in the reactance coil.

Hence when a heavy current passes through the series coil of a compound wound converter and tends to produce a leading current, the reactance coil will balance it, and improve the power factor of the whole line.

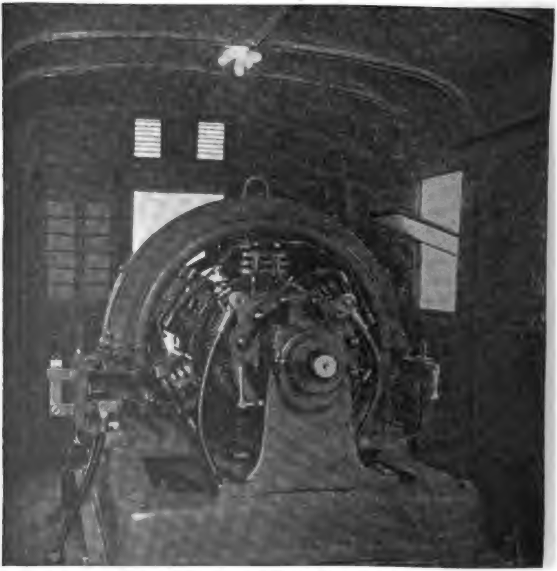


FIG. 2,780.—Westinghouse 300 kw. converter in portable sub-station.

Portable Sub-Stations.—A portable sub-station constitutes a spare equipment for practically any number of permanent sub-stations and renders unnecessary the installation of spare equipment in each.

It can be used to increase the capacity of a permanent sub-station when the load is unusually heavy, or to provide service while a permanent sub-station is being overhauled or rebuilt.

The transformer can be used for emergency lighting, the primary being connected to a high pressure line and the secondary to the load, if special provision be made at the time the transformer is built to adapt it for these applications.

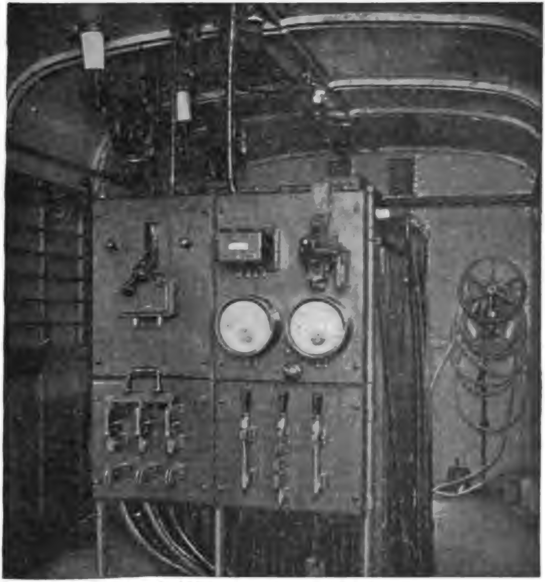
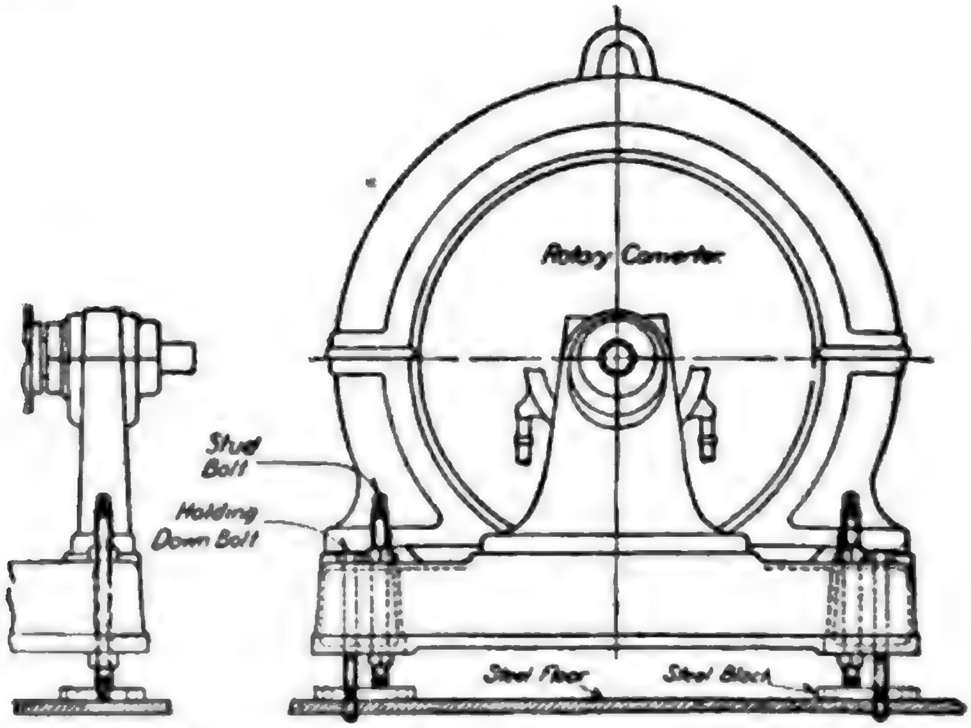


Fig. 2,781.—Switchboard end of Westinghouse portable sub-station.

When an electric railway has a portable sub-station, direct current can be provided at any point on the system where there is track at the high pressure line. The direct current can be made available very quickly as its production involves only the transferring of the sub-station, and its connection to the high pressure line.

Portable sub-stations range in capacity from 200 to 500 kw., and for all alternating current voltages up to 66,000, and frequencies of 25 and 60 cycles.

Although portable sub-stations usually must be of more or less special design to adapt them to the conditions under which they must operate, there are certain general features that are common to all. All members are readily accessible and there are no unnecessary parts. The weight and dimensions are a minimum insuring ease of transportation. Live parts are so protected that the danger of accidental contact with them is minimized.



FIGS. 2,782 and 2,783.—Views of levelling device for Westinghouse converter.

Ques. What are the advantages of using outdoor transformers on portable sub-stations?

Ans. All high pressure wiring is kept out of the car. The transformer is more effectively cooled and the heat dissipated by the transformer does not warm the interior of the cab. The transformer is much more accessible. The car can be run under a crane and the transformer coils pulled out with a hoist.

Taps for different high and low pressure voltages can be readily provided at the time the transformer is being built.

CHAPTER LXVII

MANAGEMENT

The term "management," broadly speaking, includes not only e actual skilled attention necessary for the proper operation the machines, after the plant is built, but also other duties ich must be performed from its inception to completion, and ich may be classified as

1. Selection;
2. Location;
3. Erection;
4. Testing;
5. Running;
6. Care;
7. Repair.

That is to say, someone must select the machinery, determine here each machine is to be located, install them, and then tend to the running of the machines and make any necessary pairs due to the ordinary mishaps likely to occur in operation.

These various duties are usually entrusted to more than one dividual; thus, the selection and location of the machinery is one by the designer of the plant, and requires for its proper xecution the services of an electrical engineer, or one possessing ore than simply a practical knowledge of power plants.

The erection of the machines is best accomplished by those making a specialty of this line of work, who by the nature of the undertaking acquire proficiency in methods of precision and an appreciation of the value of accuracy which is so essential in the work of aligning the machines, and which if poorly done will prove a constant source of annoyance afterward.

The attention required for the operation of the machines, embracing the running care and repair, is left to the "man in charge," who in most cases of small and medium size plants is the chief steam engineer. He must therefore, not only understand the steam apparatus, but possess sufficient knowledge o electrical machinery to operate and maintain it in prop working order.

The present chapter deals chiefly with alternating curren machinery, the management of direct current machines havin been fully explained in Guide No. 3, however, some of the matt here presented is common to both classes of apparatus.

Selection.—In order to intelligently select a machine so tha it will properly harmonize with the conditions under which i is to operate, there are several things to be considered.

1. Type;
2. Capacity;
3. Efficiency;
4. Construction.

The general type of machine to be used is, of course, depende on the system employed, that is, whether it be direct or alte nating, single or polyphase.

Thus, the voltage in most cases is fixed except on transformer s tems where a choice of voltage may be had by selecting a transform to suit.

In alternating current constant pressure transmission circuits, an average voltage of 2,200 volts with step down transformer ratios of $\frac{1}{10}$ and $\frac{1}{20}$ is in general use, and is recommended.

For long distance, the following average voltages are recommended 6,000; 11,000; 22,000; 33,000; 44,000; 66,000; 88,000; and higher, depending on the length of the line and degree of economy desired.

In alternating circuits the standard frequencies are 25, and 60 cycles. These frequencies are already in extensive use and it is recommended to adhere to them as closely as possible.

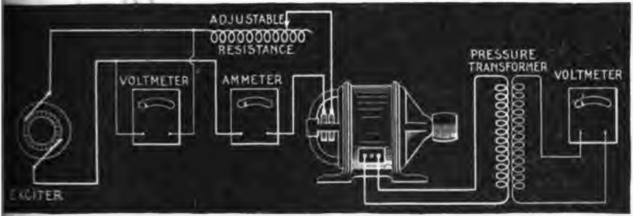


FIG. 2,784.—Diagram of connections for testing to obtain the saturation curve of an alternator. The saturation curve shows the relation between the volts generated in the armature and the amperes of field current (or ampere turns of the field) for a constant armature current. The armature current may be zero, in which case the curve is called *no load saturation curve*, or sometimes the *open circuit characteristic curve*. A saturation curve may be taken with full load current in the armature; but this is rarely done, except in alternators of comparatively small output. If a full load saturation curve be desired, it can be approximately calculated from the no load saturation curve. The figure shows the connections. If the voltage generated is greater than the capacity of the voltmeter, a multiplying coil or a step down pressure transformer may be used, as shown. A series of observations of the voltage between the terminals of one of the phases, is made for different values of the field current. Eight or nine points along the curve are usually sufficient, the series extending from zero to about fifty per cent. above normal rated voltage. The points should be taken more closely together in the vicinity of normal voltage than at other portions of the curve. Care must be taken that the alternator is run at its rated speed, and this speed must be kept constant. Deviations from constant speed may be most easily detected by the use of a tachometer. If the machine be two phase or three phase, the voltmeter may be connected to any one phase throughout a complete series of observations. The voltage of all the phases should be observed for normal full load excitation by connecting the voltmeter to each phase successively, keeping the field current constant at normal voltage. This is done in order to see how closely the voltage of the different phases agree.

In fixing the capacity of a machine, *careful consideration should be given to the conditions of operation both* **present** *and* **future** in order that the resultant efficiency may be maximum.

Most machines show the best efficiency at or near full load. If the load be always constant, as for instance, a pump forcing water to a given head, it would be a simple matter to specify the proper size c machine, but in nearly all cases, and especially in electrical plants, th load varies widely, not only the daily and hourly fluctuations, but th varying demands depending on the season of the year and growth c the plant's business. All of these conditions tend to complicate th matter, so that intelligent selection of capacity of a machine require not only calculation but mature judgment, which is only obtained b long experience.

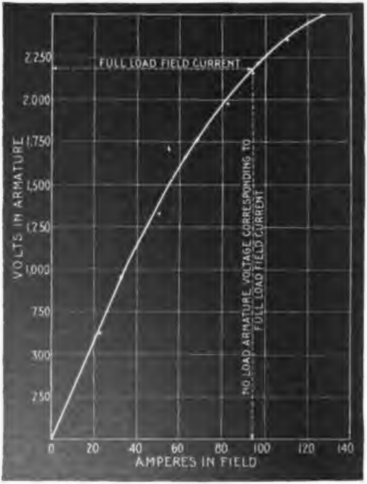


FIG. 2,785.—Saturation curve taken from a 2,000 kw., three phase alternator of the revolvin field type, having 16 poles, and generating 2,000 volts, and 576 amperes per phase when run at 300 R.P.M.

In selecting a machine, or in fact any item connected with the plant *its construction should be carefully considered.*

Standard construction should be insisted upon so that in the event of damage a new part can be obtained with the least possible delay.

The parts of most machines are *interchangeable*, that is to say, with the refined methods of machinery a duplicate part (usually carried in stock) may be obtained at once to replace a defective or broken part, and made with such precision that little or no fitting will be required.

The importance of standard construction cannot be better illustrated than in the matter of steam piping, that is, the kind of fittings selected for a given installation.

With the exception of the exhaust line from engine to condenser, where other than standard construction may sometimes be used to reduce the frictional resistance to the steam, the author would adhere to standard construction except in very exceptional cases. Those who have had practical experience in pipe fitting will appreciate the wisdom of this.

For installations in places remote from large supply houses, the more usual forms of standard fittings should be employed, such as ordinary T's, 45° and 90° elbows, etc.

In such locations, where designers specify the less usual forms of standard fittings such as union fittings, offset reducers, etc., or special fittings made to sketch, it simply means, in the first instance that they usually cannot be obtained of the local dealer, making it necessary to order from some large supply house and resulting in vexatious delays.

As a rule, those who specify special fittings have found that their making requires an unreasonable length of time, and the cost to be several times that of the equivalent in standard fittings.

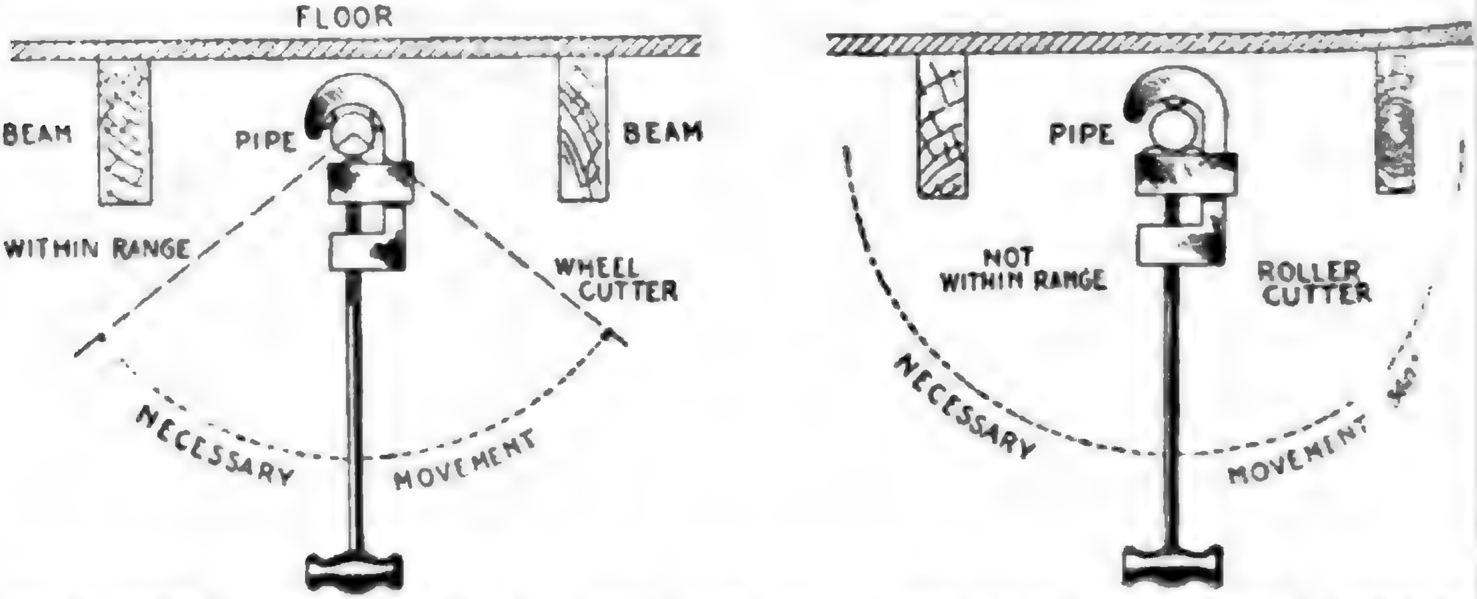
An examination of a few installations will usually show numerous special and odd shape fittings, which are entirely unnecessary.

Moreover, a standard design, in general, is better than a special design, because the former has been tried out, and any imperfection or weakness remedied, and where thousands of castings of a kind are turned out, a better article is usually the result as compared with a special casting.

In the matter of construction, in addition to the items just mentioned, it should be considered with respect to

1. Quality;
2. Range;
3. Accessibility;
4. Proportion;
5. Lubrication;
6. Adjustment.

It is poor policy, excepting in very rare instances, to buy a "cheap" article, as, especially in these days of commercial greed, the best is none too good.



Figs. 2,786 and 2,787.—Wheel and roller pipe cutters illustrating **range.** The illustrations show the comparative movements necessary with the two types of cutter to perform that function. The wheel cutter requiring only a small arc of movement will cut a pipe in an inaccessible place as shown, which with a roller cutter would be impossible. Accordingly the wheel cutter is said to have a greater *range* than the roller cutter.

Perhaps next in importance to quality, at least in most cases, is *range.* This may be defined as *scope of operation, effectiveness,* or *adaptability.* The importance of range is perhaps most pronounced in the selection of tools, especially for plants remote from repair shops.

For instance, in selecting a pipe cutter, there are two general classes: wheel cutters, and roller cutters. A wheel cutter has three wheels and a roller cutter one wheel and two rollers, the object of the rollers being

Diameter			Thickness.	Circumference.		Transverse areas.			Length of pipe per square foot of		Length of pipe containing one cubic foot.	Nominal weight per foot.	Number of threads per inch of screw.
Nominal internal.	Actual external.	Actual internal.		External.	Internal.	External.	Internal.	Metal.	External surface	Internal surface			
Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Sq. ins.	Sq. ins.	Sq. ins.	Feet.	Feet.	Feet.	Pounds.	
1/8	.405	.27	.068	1.272	.848	.129	.0573	.0717	9.44	14.15	2513.	.241	27
1/4	.54	.364	.088	1.696	1.144	.229	.1041	.1249	7.075	10.49	1383.3	.42	18
3/8	.675	.494	.091	2.121	1.552	.358	.1917	.1663	5.657	7.73	751.2	.559	18
1/2	.84	.623	.109	2.639	1.957	.554	.3048	.2492	4.547	6.13	472.4	.837	14
3/4	1.05	.824	.113	3.299	2.589	.866	.5333	.3327	3.637	4.635	270.	1.115	14
1	1.315	1.048	.134	4.131	3.292	1.358	.8626	.4954	2.904	3.645	166.9	1.668	11 1/2
1 1/4	1.66	1.38	.14	5.215	4.335	2.164	1.496	.668	2.301	2.768	96.25	2.244	11 1/2
1 1/2	1.9	1.611	.145	5.969	5.061	2.835	2.038	.797	2.01	2.371	70.66	2.678	11 1/2
2	2.375	2.067	.154	7.461	6.494	4.43	3.356	1.074	1.608	1.848	42.91	3.609	11 1/2
2 1/2	2.875	2.468	.204	9.032	7.753	6.492	4.784	1.708	1.328	1.547	30.1	5.739	8
3	3.5	3.067	.217	10.996	9.636	9.621	7.388	2.243	1.091	1.245	19.5	7.536	8
3 1/2	4.	3.548	.226	12.566	11.146	12.566	9.887	2.679	.955	1.077	14.57	9.001	8
4	4.5	4.026	.237	14.137	12.648	15.904	12.73	3.174	.849	.949	11.31	10.665	8
4 1/2	5.	4.508	.246	15.708	14.162	19.635	15.961	3.674	.764	.848	9.02	12.34	8
5	5.563	5.045	.259	17.477	15.849	24.306	19.99	4.316	.687	.757	7.2	14.502	8
6	6.625	6.065	.28	20.813	19.054	34.472	28.888	5.584	.577	.63	4.98	18.762	8
7	7.625	7.023	.301	23.955	22.063	45.664	38.738	6.926	.501	.544	3.72	23.271	8
8	8.625	7.982	.322	27.096	25.076	58.426	50.04	8.386	.443	.478	2.88	28.177	8
9	9.625	8.937	.344	30.238	28.076	72.76	62.73	10.03	.397	.427	2.29	33.701	8
10	10.75	10.019	.366	33.772	31.477	90.763	78.839	11.924	.355	.382	1.82	40.065	8
11	12.	11.25	.375	37.699	35.343	113.098	99.402	13.696	.318	.339	1.456	45.95	8
12	12.75	12.	.375	40.055	37.7	127.677	113.098	14.579	.299	.319	1.27	48.985	8

to keep the wheel perpendicular to the pipe in starting the cut and to reduce burning. It must be evident that in operation, a roller cutter requires sufficient roomaround the pipe to permit making a complete revolution of the cutter, whereas, with a wheel cutter, the work may be done by moving the cutter back andforth through a small arc, as illustrated in figs. 2,786 and 2,787. Thus a wheel cutter has a *greater range* than a roller cutter.

Range relates not only to ability to operate in inaccessible places but to the various operations that may be performed by one tool.

Open construction should be employed, wherever possible, so that all parts of a machine that require attention, or that may become deranged in operation, may be accessible for adjustment or repair.

The design should be such that there is ample strength, and the bearings for moving parts should be of liberal proportions to avoid heating with minimum attention.

A comparison of the proportions used by different manufacturers for a machine of given size might profitably be made before a selection is made.

The matter of lubrication is important.

Fast running machines, such as generators and motors, should be provided with ring oilers and oil reservoirs of ample capacity, as shown in figs. 2,788 to 2,794.

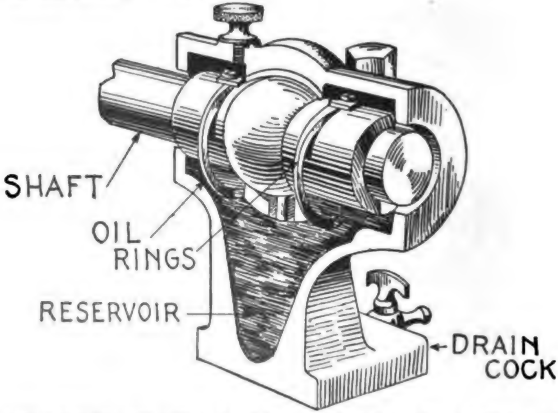
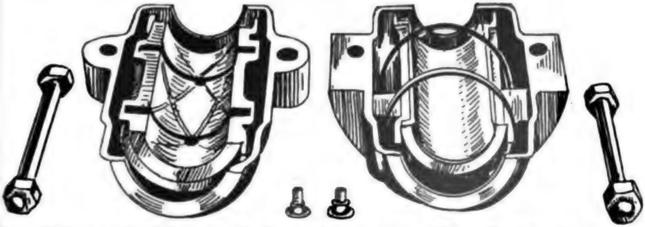


FIG. 2,788.—Sectional view showing a ring oiler or self oiling bearing. As shown the pedestal or bearing standard is cored out to form a reservoir for the oil. The rings are in rolling contact with the shaft, and dip at their lower part into the oil. In operation, oil is brought up by the rings which revolve because of the frictional contacts with the shaft. The oil is in this way brought up to the top of the bearing and distributed along the shaft gradually descending by gravity to the reservoir, being thus used over and over. A drain cock, is provided in the base so that the oil may be periodically removed from the reservoir and strained to remove the accumulation of foreign matter. This should be frequently done to minimize the wear of the bearing.

All bearings subject to appreciable wear should be made adjustable so that lost motion may be taken up from time to time and thus keep the vibration and noise of operation within proper limits.

Selection of Generators.—This is governed by the class of work to be done and by certain local conditions which are liable to vary considerably for different stations.

These variable factors determine whether the generators must be of the direct or alternating current type, whether they must be wound to develop a high or a low voltage, and whether their outputs in amperes must be large or small. Sufficient information has already been given to cover these various cases; there are, however, certain general rules that may advantageously be observed in the selection of generators designed to fill any of the aforementioned conditions, and it is well to possess certain facts regarding their construction.



FIGS. 2,789 to 2,794.—Self oiling self aligning bearing open. Views showing oil grooves, rings, bolts etc.

Ques. Name an important point to be considered in selecting a generator.

Ans. Its efficiency.

Ques. What are the important points with respect to efficiency?

Ans. A generator possessing a high efficiency at the average load is more desirable than a generator showing a high efficiency at full load.

Ques. Why?

Ans. The reason is that in station practice the full load limit is seldom reached, the usual load carried by a generator ordinarily lying between the one-half and three-quarter load points.

Ques. How do the efficiencies of large and small generators compare?

Ans. There is little difference.

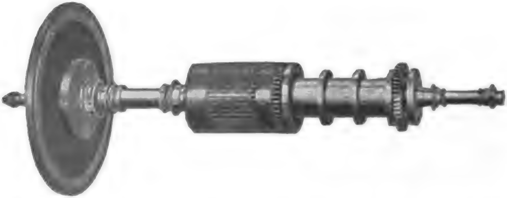


Fig. 2,795.—Rotor of Westinghouse type T turbine dynamo set. The dynamo is of the commutating pole type either shunt or compound wound. The turbine is of the single wheel impulse type. The wheel is mounted directly on the end of the shaft as shown. Steam is used two or more times on the wheel to secure efficiency. A fly ball governor is provided with weights hung on hardened steel knife edges. In case of over speeding, an automatic safety stop throttle valve is tapped shutting off the steam supply. This type of turbine dynamo set is especially applicable for exciter service in modern, superheated steam generating stations where the steam pressure exceeds 125 pounds. Westinghouse Type T turbines operate directly (that is, without a reducing valve) on pressures up to 200 pounds per square inch with steam superheated to 150 degrees Fahrenheit.

Ques. How are the sizes and number of generator determined?

Ans. The sizes and number of generator to be installed should be such as to permit the engines operating them being worked at nearly full load, because the efficiencies of the latter machines decrease rapidly when carrying less than this amount.

Ques. What is understood by regulation?

Ans. The accuracy and reliability with which the pressure or current developed in a machine may be controlled.

It is generally possible if purchasing of a reputable concern, to obtain access to record sheets on which may be found results of tests conducted on the generator in question, and as these are really the only means of ascertaining the values of efficiency and regulation, the purchaser has a right to inspect them. If, for some reason or other, he has not been afforded this privilege, he should order the machine installed in the station on approval, and test its efficiency and regulation before making the purchase.

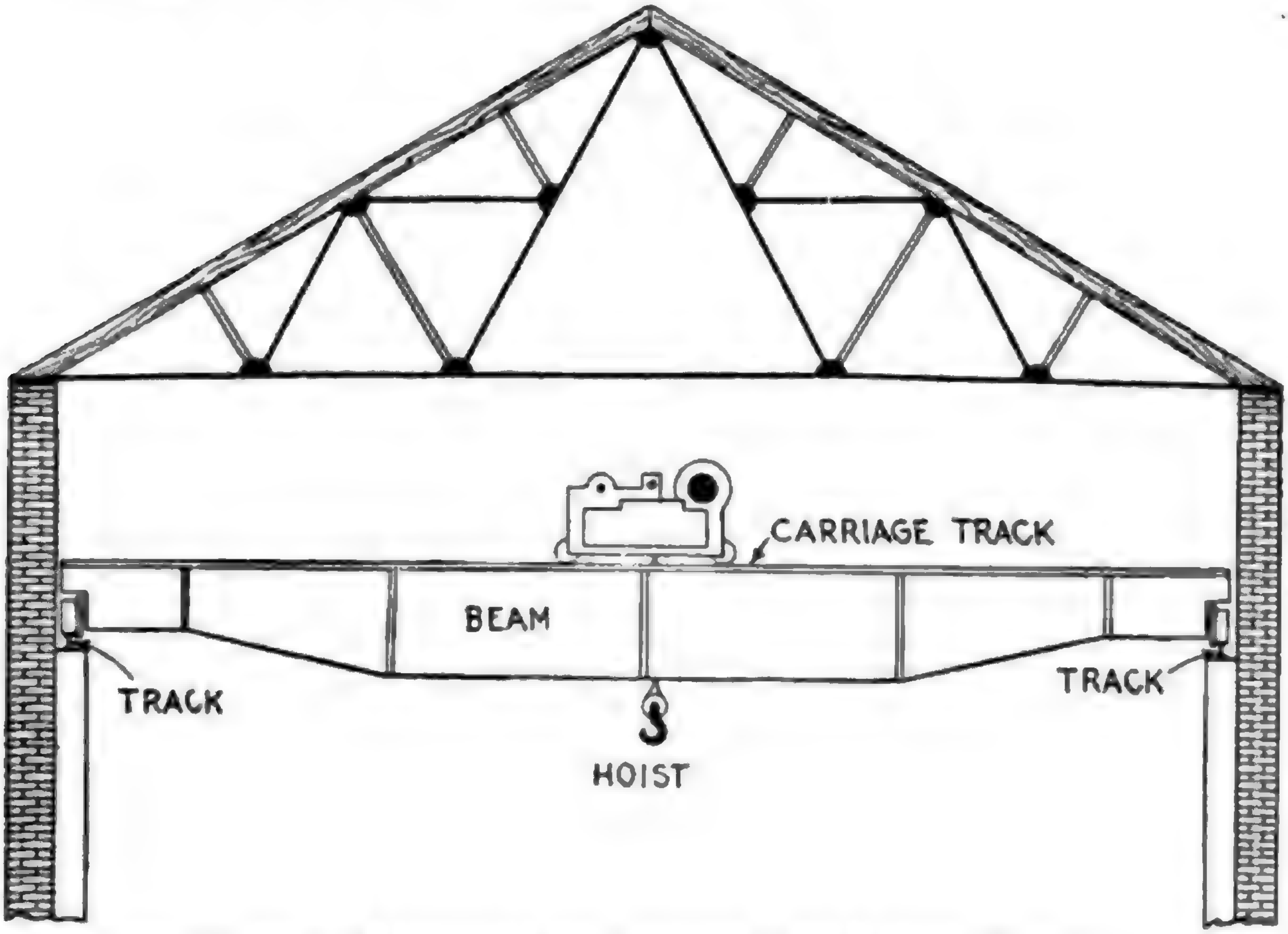


FIG. 2,796.—Cross section of electrical station showing small traveling crane.

Installation.—The installation of machines and apparatus in an electrical station is a task which increases in difficulty with the size of the plant. When the parts are small and comparatively light they may readily be placed in position, either by hand, by erecting temporary supports which may be moved from place to place as desired, or by rolling the parts along on the floor upon pieces of iron pipe. If, however, the parts be large and heavy, a traveling crane such as shown in fig. 2,797, becomes necessary.

Ques. What precaution should be taken in moving the parts of machines?

Ans. Care should be taken not to injure the bearings and shafts, the joints in magnetic circuits such as those between frame and pole pieces, and the windings on the field and armature.

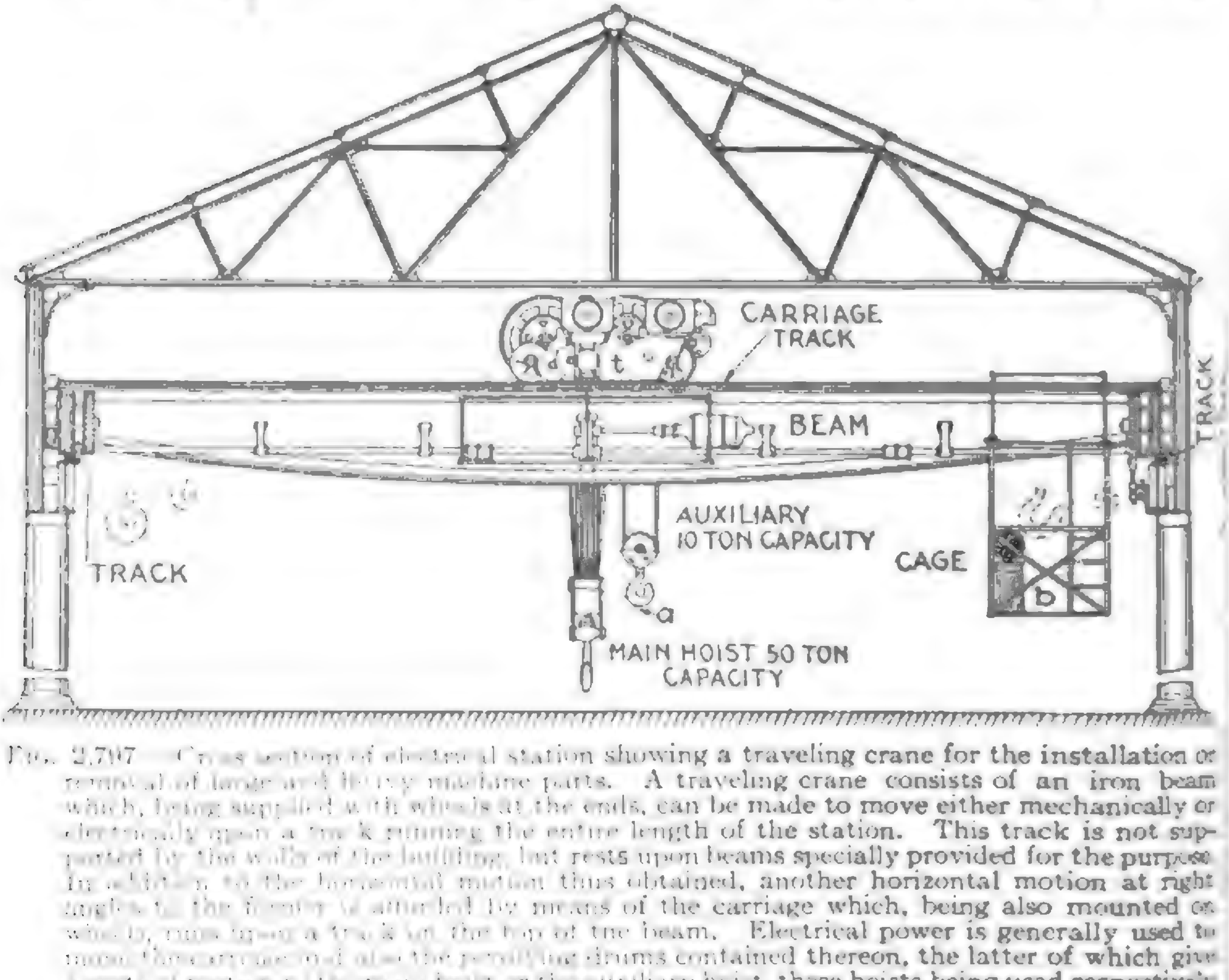


FIG. 2,797.—Cross section of electrical station showing a traveling crane for the installation or removal of large and heavy machine parts. A traveling crane consists of an iron beam which, being supplied with wheels at the ends, can be made to move either mechanically or electrically upon a track running the entire length of the station. This track is not supported by the walls of the building, but rests upon beams specially provided for the purpose. In addition to the horizontal motion thus obtained, another horizontal motion at right angles to the former is afforded by means of the carriage which, being also mounted on wheels, runs upon a track on the top of the beam. Electrical power is generally used to move the carriage and also the revolving drums contained thereon, the latter of which give a vertical motion to the main hoist or the auxiliary hoist, these hoists being used respectively for raising or lowering heavy or light loads. In the larger sizes of electric traveling crane, a cage is attached to the beam for the operator, who, by means of three controllers mounted in the cage, can move a load on either the main or auxiliary hoist in any direction.

The insulations of the windings are perhaps the most vital parts of a generator, and the most readily injured. The prick of a pin or tack, a bruise, or a bending of the wires by resting their weight upon them or by their coming in contact with some hard substance, will often render a field coil or an armature useless.

Owing to its costly construction, it is advisable when transporting armatures by means of cranes to use a wooden spreader, as shown in fig. 2,798 to prevent the supporting rope bruising the winding.

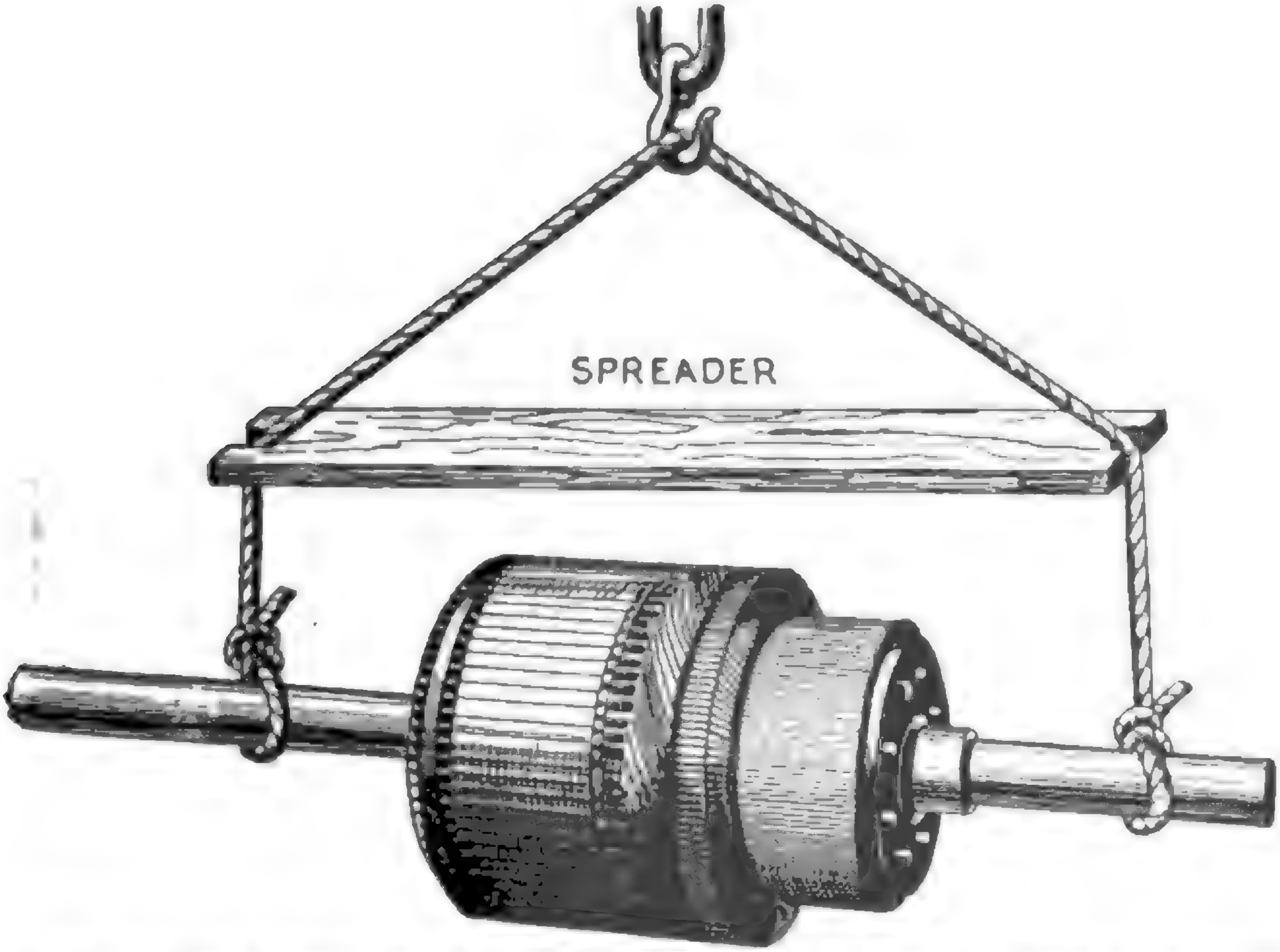


FIG. 2,798.—View of armature in transit showing use of a wooden spreader as a protection. If a chain be used in place of the rope, a padding of cloth should be placed around the armature shaft and special care taken that the chain does not scratch the commutator.

Ques. If an armature cannot be placed at once in its final position what should be done?

Ans. It may be laid temporarily upon the floor, if a sheet of cardboard or cloth be placed underneath the armature as a protection for the windings; in case the armature is not to be used for some time, it is better practice to place it in a horizontal position on two wooden supports near the shaft ends.

Ques. What kind of base should be used with a belt driven generator or motor?

Ans. The base should be provided with V ways and adjusting screws for moving the machine horizontally to take up slack in the belt, as shown in fig. 2,799.

Owing to the normal tension on the belt, there is a moment exerted equal in amount to the distance from the center of gravity of the machine to the center of the belt, multiplied by the effective pull on the belt. This force tends to turn the machine about its center of gravity. By placing the screws as shown, any turning moment, as just mentioned, is prevented.

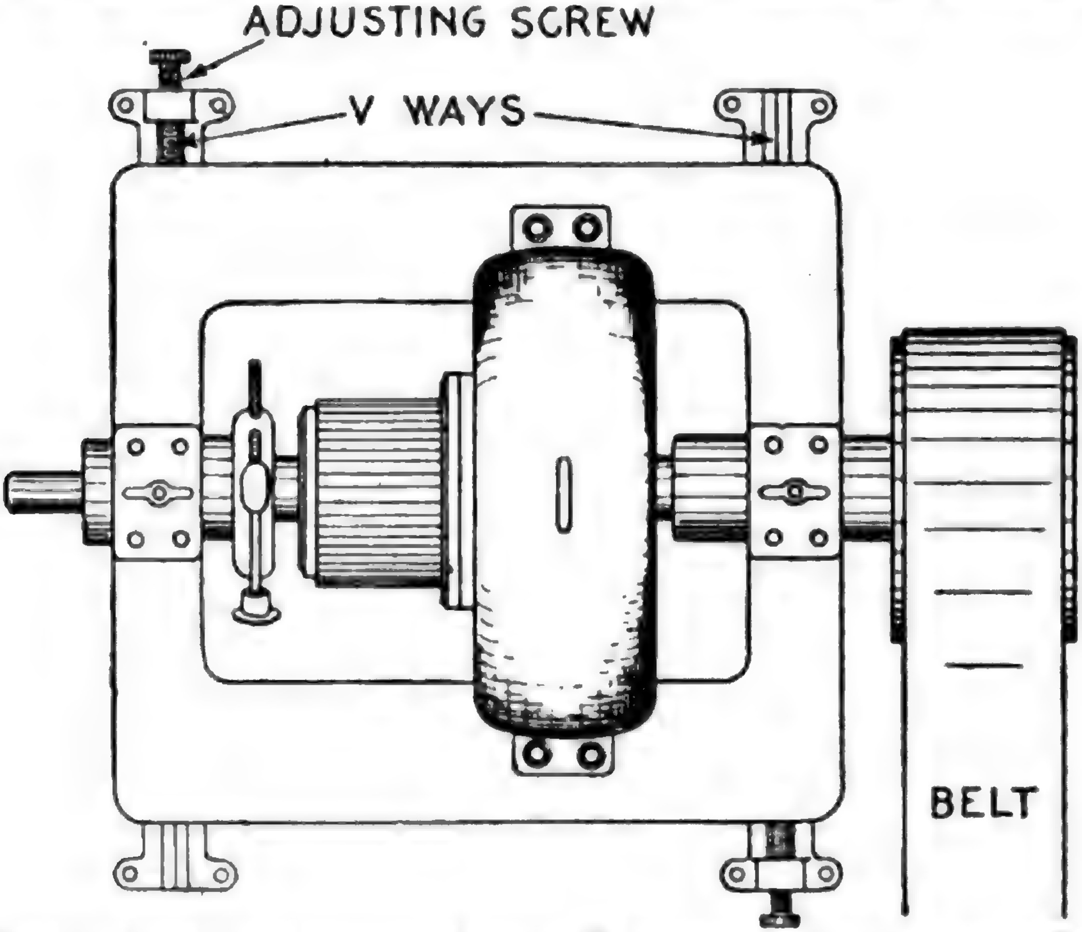
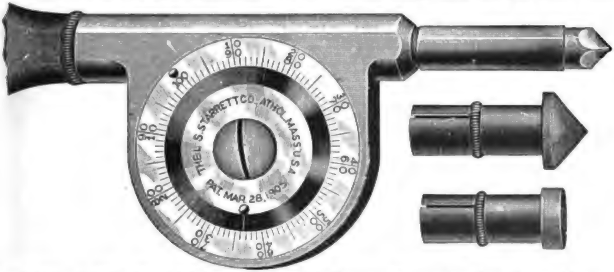


FIG. 2,799.—Plan of belt drive machine showing V ways and adjusting screws for moving the machine forward from the engine or counter shaft to take up slack in the belt.

Ques. How should a machine be assembled?

Ans. The assembling should progress by the aid of a blue print, or by the information obtained from a photograph of the complete machine as it appears when ready for service. Each part should be perfectly clean when placed in position, especially those parts between which there is friction when the machine is in operation, or across which pass lines of magnetic force; in both cases the surfaces in contact must be true and slightly oiled before placing in position.

Contact surfaces forming part of electrical circuits must also be clean and tightly screwed together. An important point to bear in mind when assembling a machine is, to so place the parts that it will not be necessary to remove any one of them in order to get some other part in its proper position. By remembering this simple rule much time will be saved, and in the majority of instances the parts will finally be better fitted together than if the task has to be repeated a number of times.



Figs. 2,800 to 2,802.—Starrett's improved speed indicator. In construction, the working parts are enclosed like a watch. The graduations show every revolution, and with two rows of figures read both right and left as the shaft may run. While looking at the watch, each hundred revolutions may be counted by allowing the oval headed pin on the revolving disc to pass under the thumb as the instrument is pressed to its work. A late improvement in this indicator consists in the rotating disc, which, being carried by friction may be moved to the starting point where the raised knobs coincide. When the spindle is placed in connection with the revolving shaft, pressing the raised knob with the thumb will prevent the disc rotating, while the hand of the watch gets to the right position to take the time. By releasing the pressure the disc is liberated for counting the revolutions of the shaft when every 100 may be noted by feeling the knob pass under the thumb lightly pressed against it, thus relieving the eye, which has only to look on the watch to note the time.

When there are two or more parts of the machine similarly shaped, it is often difficult to properly locate them, but in such cases notice should be taken of the factory marks usually stamped upon such pieces and their proper places determined from the instructions sent with the machine.

Ques. What should be noted with respect to speed of generator?

Ans. Each generator is designed to be run at a certain speed in order to develop the voltage at which the machine is rated. The speed, in revolutions per minute, the pressure in volts, and the capacity or output in watts (volts × amperes) or in kilowatts (thousands of watts) are generally stamped on a nameplate screwed to the machine.

This requirement frequently requires calculations to be made by the erectors to determine the proper size pulleys to employ to obtain the desired speed.

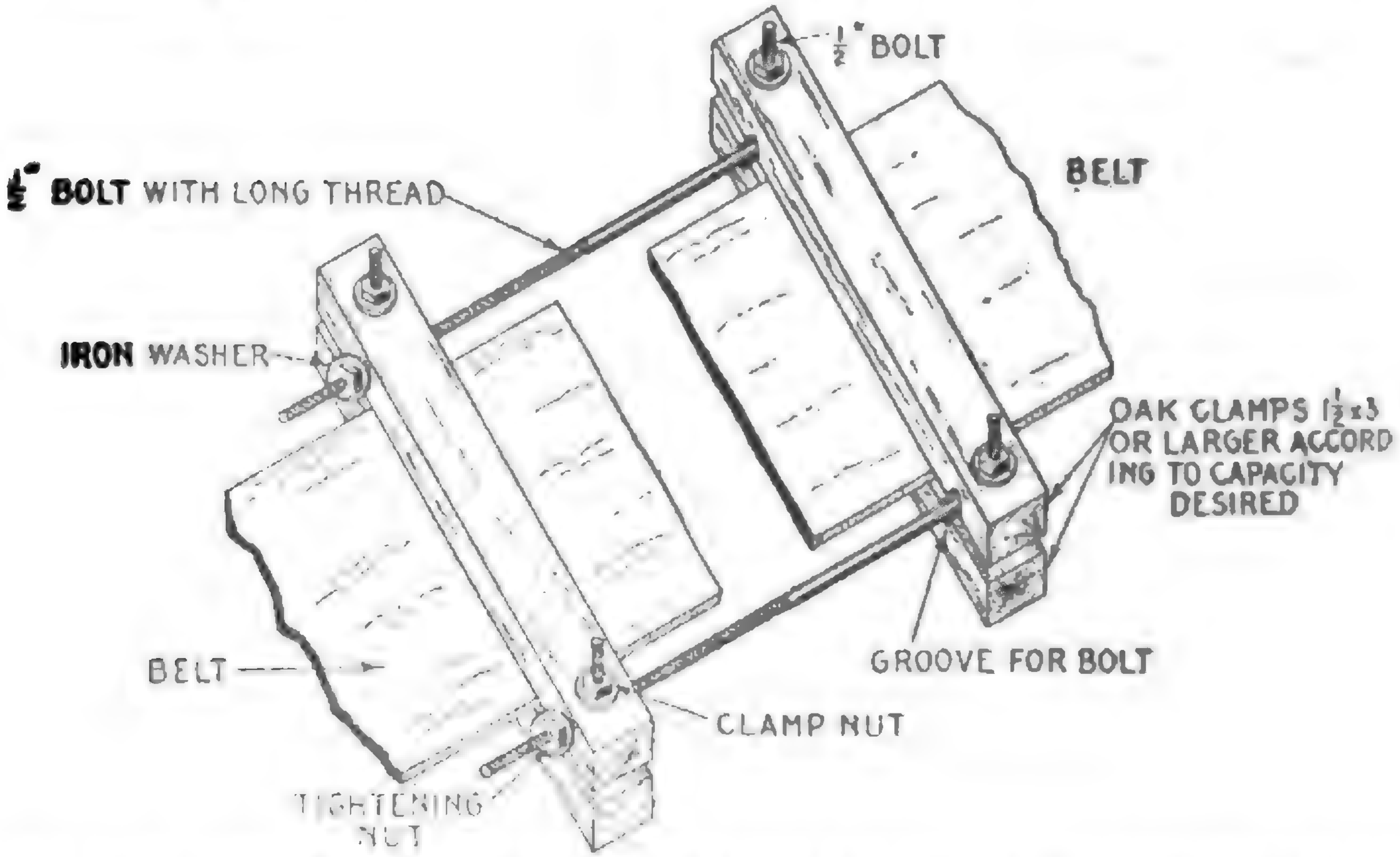

½" BOLT
BELT
½" BOLT WITH LONG THREAD
IRON WASHER
OAK CLAMPS 1½x3 OR LARGER ACCORDING TO CAPACITY DESIRED
BELT
GROOVE FOR BOLT
CLAMP NUT
TIGHTENING NUT

FIG. 2,803.—Home made belt clamp. It is made with four pieces of oak of ample size to firmly grip the belt ends where the bolts are tightened. The figure shows the clamp complete and in position on the belt and clearly illustrates the details of construction. In making the long bolts the thread should be cut about three-quarter length of bolt and deep enough so that the nuts will easily screw on.

Example.—What diameter of engine pulley is required to run a dynamo at a speed of 1,450 revolutions per minute the dynamo pulley being 10 inches in diameter and the speed of engine, 275 revolutions per minute?

The diameter of pulley required on engine is

$$10 \times \frac{1,450}{275} = 53 \text{ inches, nearly.}$$

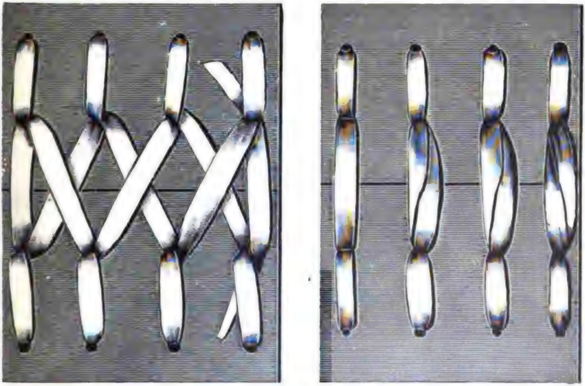
Rule.—To find the diameter of the driving pulley, ***multiply the speed of the driven pulley by its diameter, divide the product by the speed of the driver and the answer will be the size of the driver required.***

Example.—If the speed of an engine be 325 revolutions per minute, diameter of engine pulley 42 inches, and the speed of the dynamo 1,400 revolutions per minute, how large a pulley is required on dynamo?

The size of the dynamo pulley is

$$42\times\frac{325}{1,400}=9\tfrac{3}{4}\text{ inches.}$$

Rule.—To find the size of dynamo pulley, ***multiply the speed of engine by the diameter of engine wheel and divide the product by the speed of the dynamo.***



FIGS. 2,804 and 2,805.—A good method of lacing a belt. The view at the left shows outer side of belt, and at the right, inner or pulley side.

Example.—If a steam engine, running 300 revolutions per minute, have a belt wheel 48 inches in diameter, and be belted to a dynamo having a pulley 12 inches in diameter, how many revolutions per minute will the dynamo make?

The speed of dynamo will be

$$300\times\frac{48}{12}=1,200\text{ rev. per min.}$$

Rule.—When the speed of the driving pulley and its diameter are known, and the diameter of the driven pulley is known, the speed of the driven pulley is found by ***multiplying the speed of the driver by its diameter in inches and dividing the product by the diameter of the driven pulley.***

Example.—What will be the required speed of an engine having a belt wheel 46 inches in diameter to run a dynamo 1,500 revolutions per minute, the dynamo pulley being 11 inches in diameter?

The speed of the engine is

$$1{,}500 \times \frac{11}{46} = 359 \text{ rev. per min. nearly.}$$

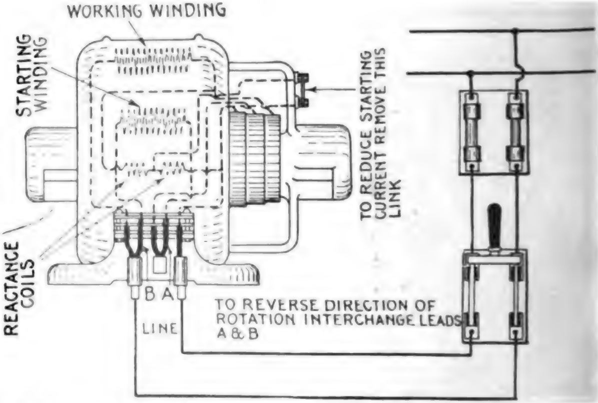
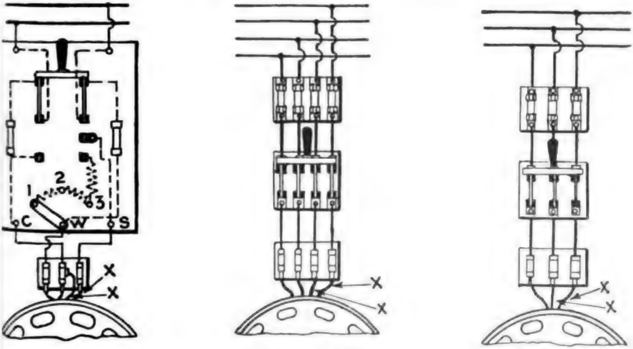

WORKING WINDING
STARTING WINDING
TO REDUCE STARTING CURRENT REMOVE THIS LINK
REACTANCE COILS
B
A
LINE
TO REVERSE DIRECTION OF ROTATION INTERCHANGE LEADS A & B

FIG. 2,806.—Wiring diagram and directions for operating Holzer-Cabot single phase self-starting motor. **Location:** The motor should be placed in as clear and dry a location as possible, away from acid or other fumes which would attack the metal parts or insulation, and should be located where it is easily accessible for cleaning and oiling. **Erection:** The motor should be set so that the shaft is level and parallel with the shaft it is to drive so that the belt will run in the middle of the pulleys. Do not use a belt which is too heavy or too tight for the work it has to do, as it will materially reduce the output of the motor. The belt should be from one-half to one inch narrower than the pulley. **Rotation:** In order to reverse the direction of rotation, interchange leads A and B. **Suspended Motors:** Motors with ring oil bearings may be used on the wall or ceiling by taking off end caps and revolving 90 or 180 degrees until the oil wells come directly below the bearings. **Starting:** Motors are provided with link across two terminals on the upper right hand bracket at the front of the motor and with this connection should start considerable overloads. If the starting current be too great with this connection, it may be reduced by removing the link. **Temperatures:** At full load the motor will feel hot to the hand, but this is far below the danger point. If too hot for touch, measure temperature with a thermometer by placing bulb against field winding for 10 minutes, covering thermometer with cloth or waste. The temperature should not exceed 75 degrees Fahr. above the surrounding air. **Oiling:** Fill the oil wells to the overflow before starting and keep them full. See that the oil rings turn freely with shaft. **Care:** The motor must be kept clean. Smooth collector rings with sandpaper and see that the brushes make good contact. When brushes become worn they may be reversed. When fitting new brushes or changing them always sandpaper them down until they make good contact with the collector rings, by passing a strip of sandpaper beneath the brush.

Rule.—To find the speed of engine when diameter of both pulleys, and speed of dynamo are given, *multiply the dynamo speed by the diameter of its pulley and divide by the diameter of engine pulley.*

Ques. How are the diameters and speeds of gear wheels igured?

Ans. The same as belted wheels, using either the pitch circle iameters or number of teeth in each gear wheel.



SINGLE PHASE TWO PHASE THREE PHASE

IGS. 2,807 to 2,809.—**Wiring diagrams and directions for operating Holzer-Cabot slow speed alternating current motors. Erecting**: In installing the motor, be sure the transformer and wiring to the motor are large enough to permit the proper voltage at the terminals. If too small, the voltage will drop and reduce the capacity of the motor. **Oiling**: Maintain oil in wells to the overflow. **Starting**: **Single phase** motors are started by first throwing the starting switch down into the starting position, and when the motor is up to speed, throwing it up into the running position. *Do not hold the switch in starting position over 10 seconds.* Starter for single phase motors above ⅙ H.P. are arranged with an adjusting link at the bottom of the panel. The link is shown in the position of least starting torque and current. Connect from W to 2 or W to 3 for starting heavier loads. *Two or three phase* motors are started simply by closing the switch. These motors start full load without starters. The motor should start promptly on closing the switch. It should be started the first time without being coupled to the line shaft. If the motor start free, but will not start loaded, it shows either that the load upon the motor is too great, the line voltage too low, or the frequency too high. The voltage and frequency with the motor running should be within 5% of the name plate rating and the voltage with 10 to 15% while starting. If the motor do not start free, either it is getting no current or something is wrong with the motor. In either case an electrician should be consulted. **Solution**: To reverse the direction of rotation interchange the leads marked "XX" in the diagrams. **Temperature:** At full load the motor should not heat over 75 degrees Fahr. above the temperature of the surrounding air; if run in a small enclosed space with no ventilation, the temperature will be somewhat higher.

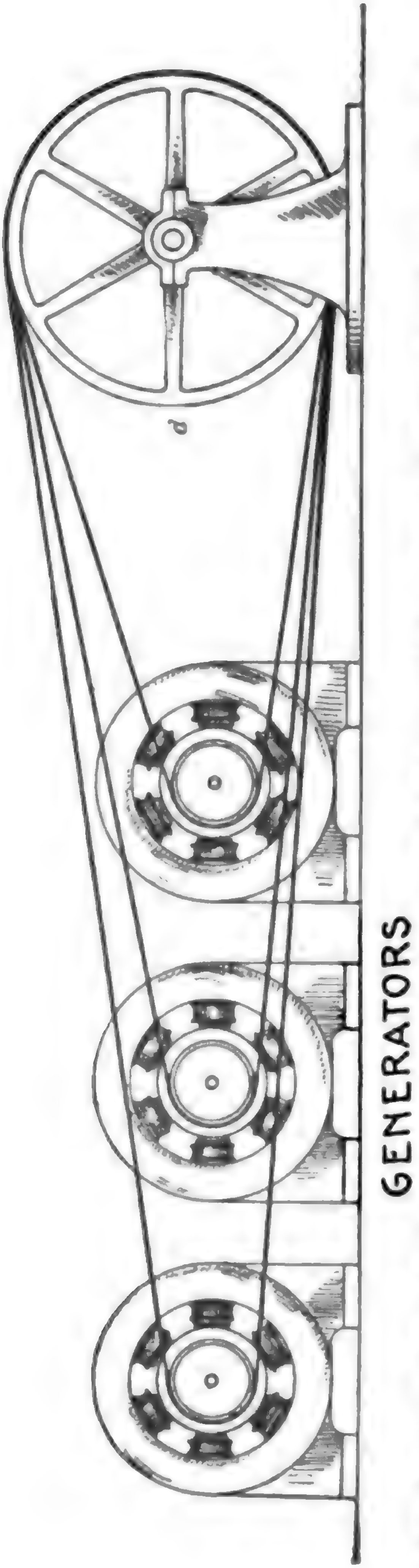


Fig. 2,810.—Tandem drive for economizing floor space with belt transmission. Belts of different lengths are used, as shown, each of which passes over the driving wheel *d* of the engine, and then over the pulley wheel of one of the generators. In such an arrangement the belts would be run lengthwise through the room in which the machines are placed, and it is obvious that since the width of the room would be governed by the width of the machines thus installed, this method is a very efficient one for accomplishing the end in view.

Ques. What should be noted with respect to generator pulleys?

Ans. A pulley of certain size is usually supplied with each generator by its manufacturer, and it is not generally advisable to depart much from the dimensions of this pulley. Accordingly, the solution of the pulley problem usually consists in finding the necessary diameter of the driving pulley relative to that of the pulley on the generator in order to furnish the required speed.

Ques. What is the chief objection to belt drive?

Ans. The large amount of floor space required.

Ques. How may the amount of space that would ordinarily be required for belt drive, be reduced?

Ans. By driving machines in tandem as in fig. 2,810, or by the double pulley drive as in fig. 2,811.

Ques. What is the objection to the tandem method?

Ans. The most economical distance between centers cannot e employed for all machines.

Ques. What is the objectionable tendency in resorting o floor economy methods with belt transmission?

Ans. The tendency to place the machines too closely together. This is poor economy as it makes the cleaning of the machines a difficult and dangerous task; it is therefore advisable to allow ufficient room for this purpose regardless of the method of elting employed.

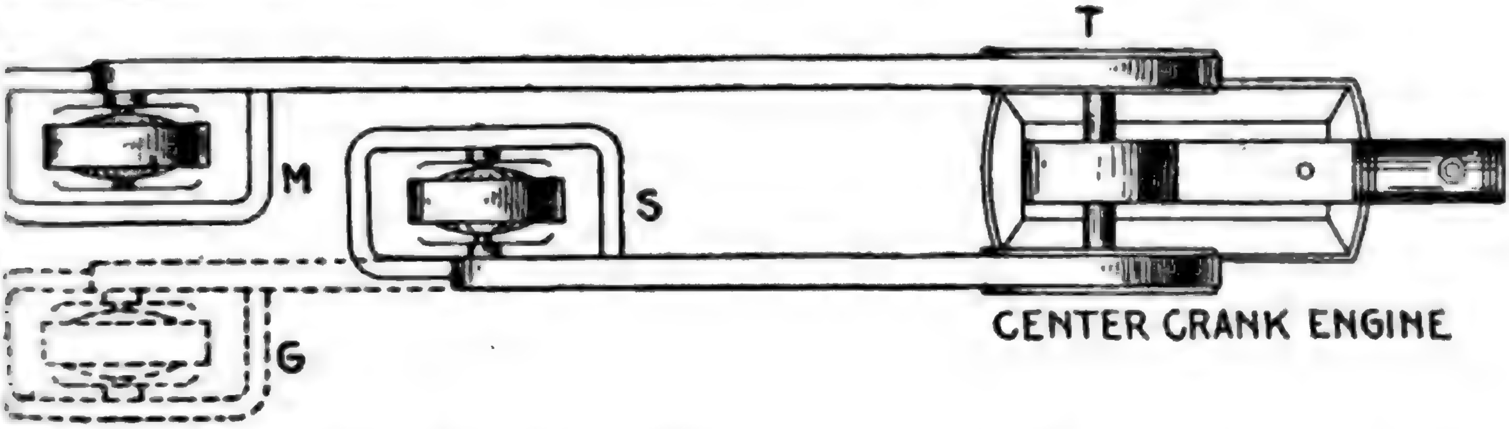


FIG. 2,811.—Double pulley drive for economizing floor space with belt transmission. Where a center crank engine is used both pulleys may be employed by belting a machine to each as shown. Although considerable floor space would be saved by the use of this scheme if the generators thus belted were placed at M and G yet still more floor space would be saved by having them occupy the positions indicated at M and S.

Ques. What is the approved location for an alternator exciter?

Ans. To economize floor space the exciter may be placed between the alternator and engine at S in fig. 2,811.

Belts.—In the selection of a belt, the quality of the leather should be first under consideration. The leather must be firm, yet pliable, free from wrinkles on the grain or hair side, and of an even thickness throughout.

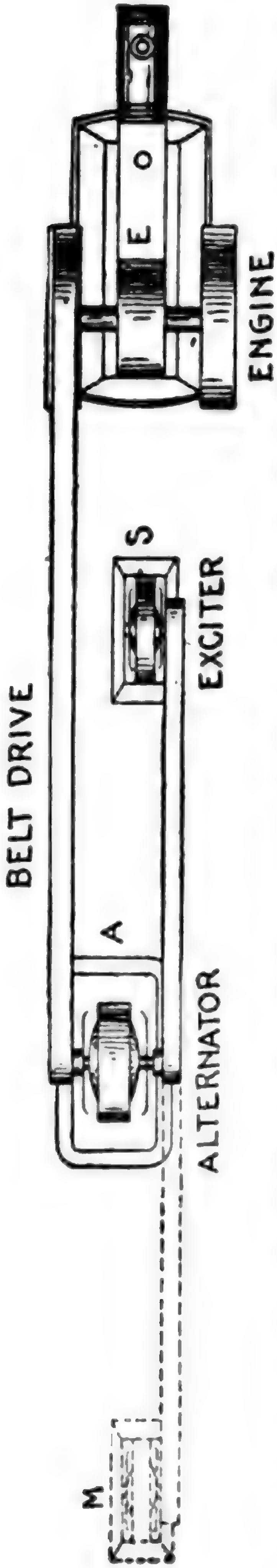


FIG. 2,812.—Separately excited belt driven alternator showing approved location of exciter. In an electrical station where alternating current is generated, the alternators for producing the current generally require separate excitation for their field windings; that is, it is usually necessary to install in conjunction with an alternator a small dynamo for supplying current to the alternator field. The exciter is a comparatively small machine; in fact, it requires only about 1 per cent. of the capacity of the alternator which it excites, and so being small is often belted to an auxiliary pulley mounted on the alternator shaft. Considerable floor space would be occupied by an installation of this nature if the exciter be placed at M, and belted to the alternator as indicated by the dotted lines. By locating the exciter at S, between the alternator and the engine, much floor space will be saved and the general appearance of the installation improved.

If the belt be well selected and properly handled, it should do service for twenty years, and even then if the worn part be cut off, the remaining portion may be remade and used again as a narrowe and shorter belt.

Besides leather belts, there are thos made of rubber which withstand moisture much better than leather belts, an which also possess an excellent grip o the pulley; they are, however, mor costly and much less durable unde normal conditions.

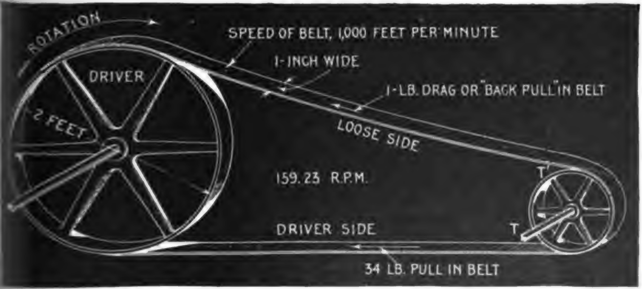
In addition to leather and rubbe belts, there are belts composed of cotton, of a combination of cotton an leather, and of rope. The leather belt however, is the standard and is to b recommended.

Equally important with the quality of a belt is its size in order t transmit the necessary power.

The average strain under which leather will break has been found b many experiments to be 3,200 pound per square inch of cross section. good quality of leather will sustain somewhat greater strain. In use o the pulleys, belts should not be subjected to a greater strain than oneeleventh their tensile strength, or abou 290 pounds to the square inch or cros section. This will be about 55 poun average strain for every inch in widt of single belt three-sixteenths inc thick. The strain allowed for a widths of belting—single, light double, and heavy double—is in direct proportion to the thickness of the belt.

Ques. How much horse power will a belt transmit?

Ans. The capacity of a belt depends on, its width, speed, and thickness. *A single belt one inch wide and travelling* 1,000 *feet per minute will transmit one horse power; a double belt under the same conditions, will transmit two horse power.*


ROTATION
SPEED OF BELT, 1,000 FEET PER MINUTE
1-INCH WIDE
1-LB. DRAG OR "BACK PULL" IN BELT
DRIVER
2 FEET
LOOSE SIDE
159.23 R.P.M.
T'
T
DRIVER SIDE
34 LB. PULL IN BELT

2,813.—One horse power transmitted by belt to illustrate the rule given above. A pulley is driven by a belt by means of the friction between the surfaces in contact. Let T be the tension on the driving side of the belt, and T', the tension on the loose side; then the driving force $=T-T'$. In the figure T is taken at 34 lbs. and T' at 1 lb.; hence driving force $=34-1=33$ lbs. Since the belt is travelling at a velocity of 1,000 feet per minute the power transmitted $=33$ lbs. $\times 1{,}000$ ft. $=33{,}000$ ft. lbs. per minute $=1$ horse power.

This corresponds to a working pull of 33 and 66 lbs. per inch of width respectively.

Example.—What width double belt will be required to transmit 50 horse power travelling at a speed of 3,000 feet per minute?

The horse power transmitted by each inch width of double belt travelling at the stated speed is

$$\left(1\times\frac{3{,}000}{1{,}000}\right)\times 2=6,$$

nce the width of belt required to transmit 50 horse power is

$$50\div 6=8.33, \text{ say 8 inches.}$$

Ques. At what velocity should a belt be run?

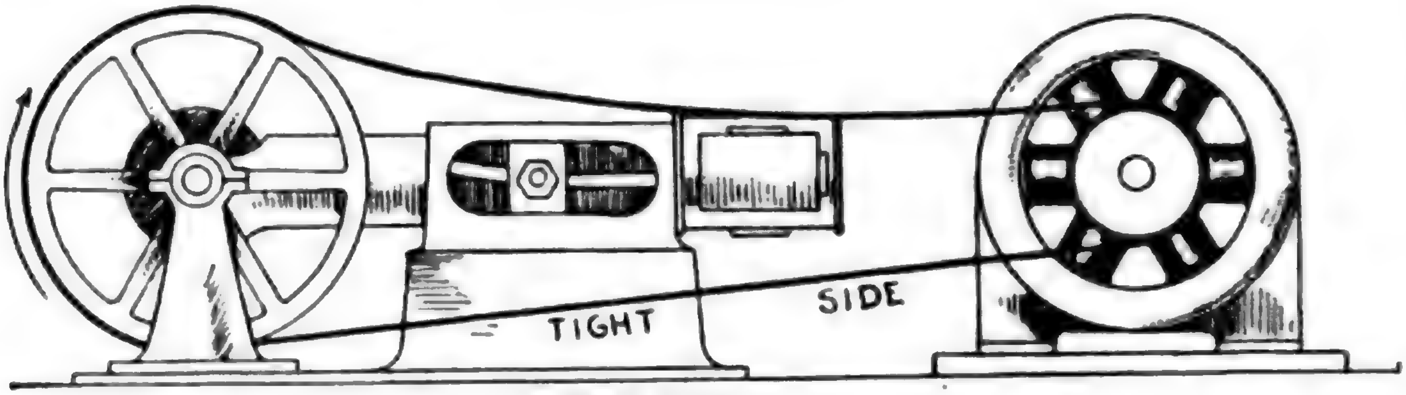
Ans. At from 3,000 to 5,000 feet per minute.

Ques. How may the greatest amount of power transmitting capacity be obtained from belts?

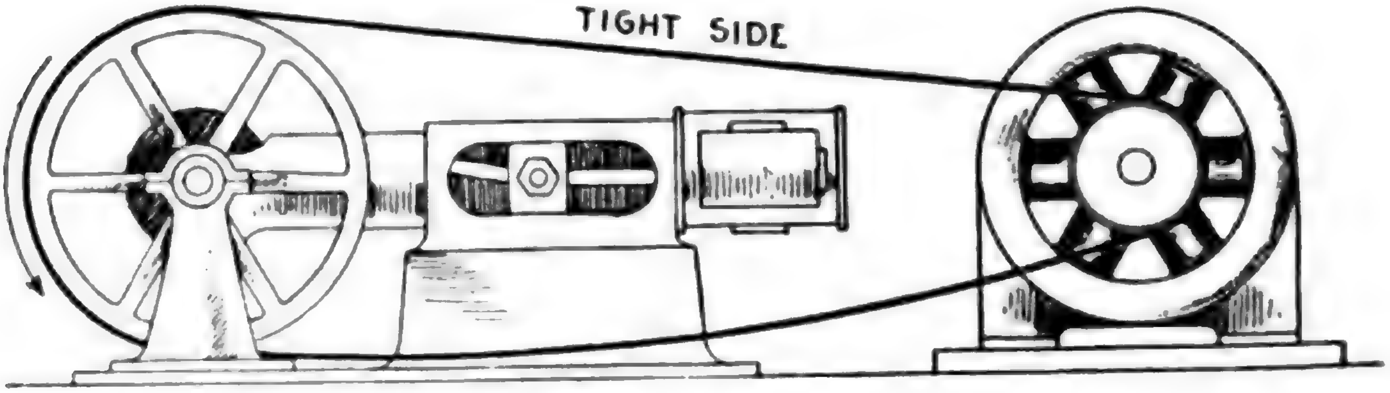
Ans. By covering the pulleys with leather.

Ques. How should belts be run?

Ans. With the tight side underneath as in fig. 2,814.



RIGHT WAY



WRONG WAY

Figs. 2,814 and 2,815.—Right and wrong way to run a belt. The tight side should be unde neath so as to increase the arc of contact and consequently the adhesion, that is to say, *better grip*, is in this way obtained.

Ques. What is a good indication of the capacity of belt in operation?

Ans. Its appearance after a few days' run.

If the side of the belt coming in contact with the pulley assume mottled appearance, it is an indication that the capacity of the belt considerably in excess of the power which it is transmitting, inasmuc as the spotted portions of the belt do not touch the pulley; and in consequence of this there is liable to be more or less slipping.

Small quantities of a mixture of tallow and fish oil which have previously been melted together in the proportion of two of the former to one of the latter, will, if applied to the belt at frequent intervals, do much toward softening it, and thus by permitting its entire surface to come in contact with the pulley, prevent any tendency toward slipping. The best results are obtained when the smooth side of the belt is used next to the pulley, since tests conducted in the past prove that more power is thus transmitted, and that the belt lasts longer when used in this way.

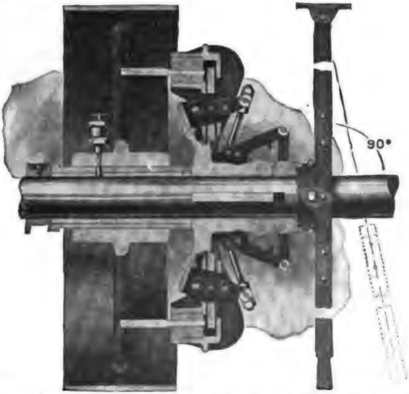


FIG. 2,816.—The Hill friction clutch pulley for power control. The clutch mechanism will start a load equivalent to the double belt capacity of the pulley to which the clutch is attached.

Ques. What is the comparison between the so called endless belts and laced belts?

Ans. With an endless belt there is no uneven or noisy action as with laced belts, when the laced joint passes over the pulleys, and the former is free from the liability of breakage at the joint.

Ques. How should a belt be placed on the pulleys?

Ans. The belt should first be placed on the pulley at rest, and then run on the other pulley while the latter is in motion.

The best results are obtained, and the strain on the belt is less, when the speed at which the moving pulley revolves is comparatively low. With heavy belts, particular care should be taken to prevent any portion of the clothing being caught either by the moving belt or pulleys, as many serious accidents have resulted in the past from carelessness in regard to this important detail. The person handling the belt should, therefore, be sure of a firm footing, and when it is impossible to secure this, it is advisable to stop the engine and fit the belt around the engine pulley as well as possible by the aid of a rope looped around the belt.

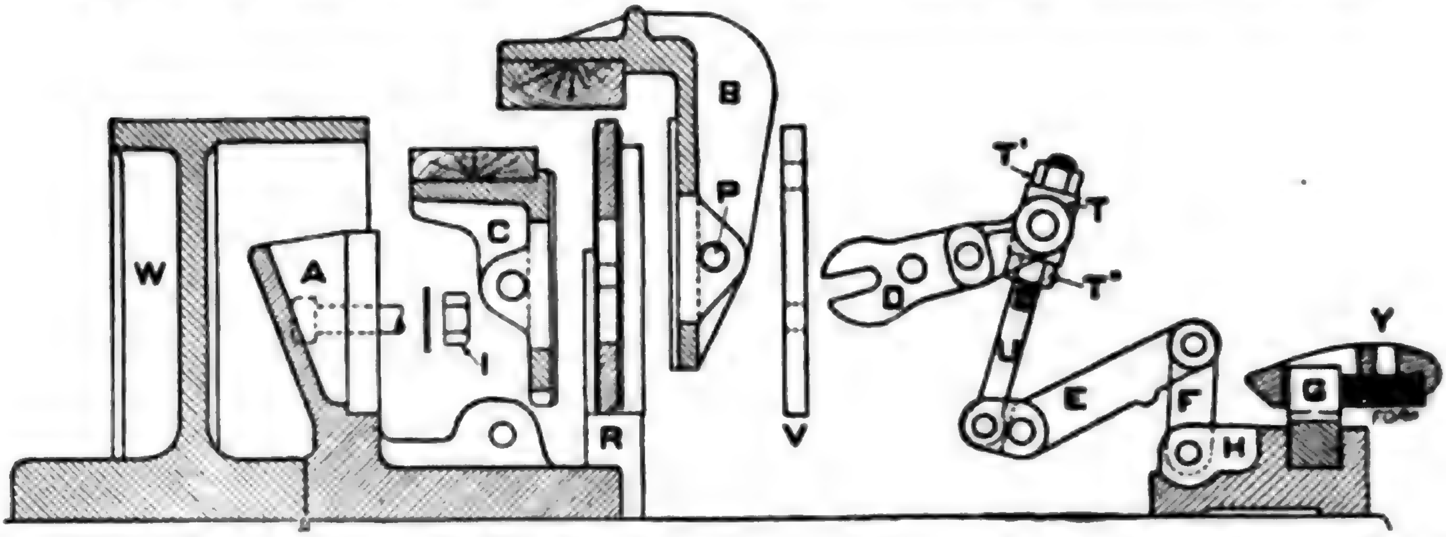


FIG. 2,817.—Sectional view of Hill clutch mechanism. In every case the mechanism hub A, and in a clutch coupling the ring W, is permanently and rigidly secured to the shaft and need not be disturbed when removing the wearing parts. When erected, the adjustment should be verified, and always with the clutch and ring engaged and at rest. If the jaws do not press equally on the ring, or if the pressure required on the cone be abnormal, loosen the upper adjusting nuts T' on eye bolts and set up the lower adjusting nuts T'' until each set of jaws is under the same pressure. Should the clutch then slip when started it is evident that the jaw pressure is insufficient and a further adjustment will be necessary. All clutches are equipped throughout with split lock washers. Vibration or shock will not loosen the nuts if properly set up. The jaws can be removed parallel to the shaft as follows: Remove the gibs V, and withdraw the jaw pins P, then pull out the levers D. Do not disturb the eye bolt nuts T' and T''. The outside jaws B can now be taken out. Remove the bolt nuts I allowing the fulcrum plates R to be taken off. On the separable hub pattern the clamping bolts must be taken out before fulcrum plate is removed. The inside jaws C may now be withdrawn. Always set the clutch operating lever in the position as shown in fig. 2,816 to avoid interference with mechanism parts. Oil the moving parts of the clutch. Keep it clean. Examine at regular intervals.

Ques. Under what conditions does a belt drive give the best results?

Ans. When the two pulleys are at the same level.

If the belt must occupy an inclined position it should not form a greater angle than 45 degrees with the horizontal.

Ques. What is a characteristic feature in the operation of belts, and why?

Ans. Belts in motion will always run to the highest side of a pulley; this is due partially to the greater speed in feet per minute developed at that point owing to the greater circumference of the pulley, and also to the effects of centrifugal force.

If, therefore, the highest sides of both pulleys be in line with each other, and the shafts of the respective pulleys be parallel to each other, there will be no tendency for the belt to leave the pulleys when once in its proper position. In order that these conditions be maintained, the belt should be no more than tight enough to prevent slipping, and the distance between the centers of the pulleys should be approximately 3.5 times the diameter of the larger one.

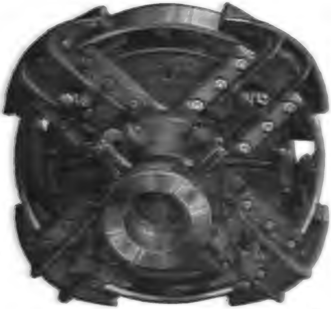


FIG. 2,818.—Hill clutch mechanism Smith type. The friction surfaces are wood to iron, the wood shoes being made from maple. All parts of the toggle gear are of steel and forgings with the exception of the connection lever which is of cast iron.

Ques. What minor appurtenances should be provided in a station?

Ans. Apparatus should be installed as a prevention against accidents, such as fire, and protection of attendants from danger.

In every electrical station there should be a pump, pipes and hose; the pump may be either directly connected to a small electric motor or belted to a countershaft, while the pipes and hose should be so placed that no water can accidentally reach the generators and electrical circuits.

A number of fire bucket filled with water should be placed on brackets around the station, and with these there should be an equal number of bucket containing dry sand, the water being used for extinguishing fire occurring at a distance from the machines and conductors, and the sand for extinguishing fire in current carrying circuits where water would cause more harm than benefit. To prevent the sand being blown about the station, each sand bucket, when not in use, should be provided with a cover.

Neat cans and boxes should be mounted in convenient places for greasy rags, waste, nuts, screws, etc., which are used continually and which therefore cannot be kept in the storeroom.

While it is important to guard against fire in the station, it is equally necessary to provide for personal safety. All passages and dark pits should therefore be thoroughly lighted both day and night, and obstacle of any nature that are not absolutely necessary in the operation of th station, should be removed. Moving belts, and especially those passin through the floor, should be enclosed in iron railings. If high voltage be generated, it is well to place a railing about the switchboard to preven accidental contact with current carrying circuits, and in such cases it i also advisable to construct an insulated platform on the floor in front c the switchboard.

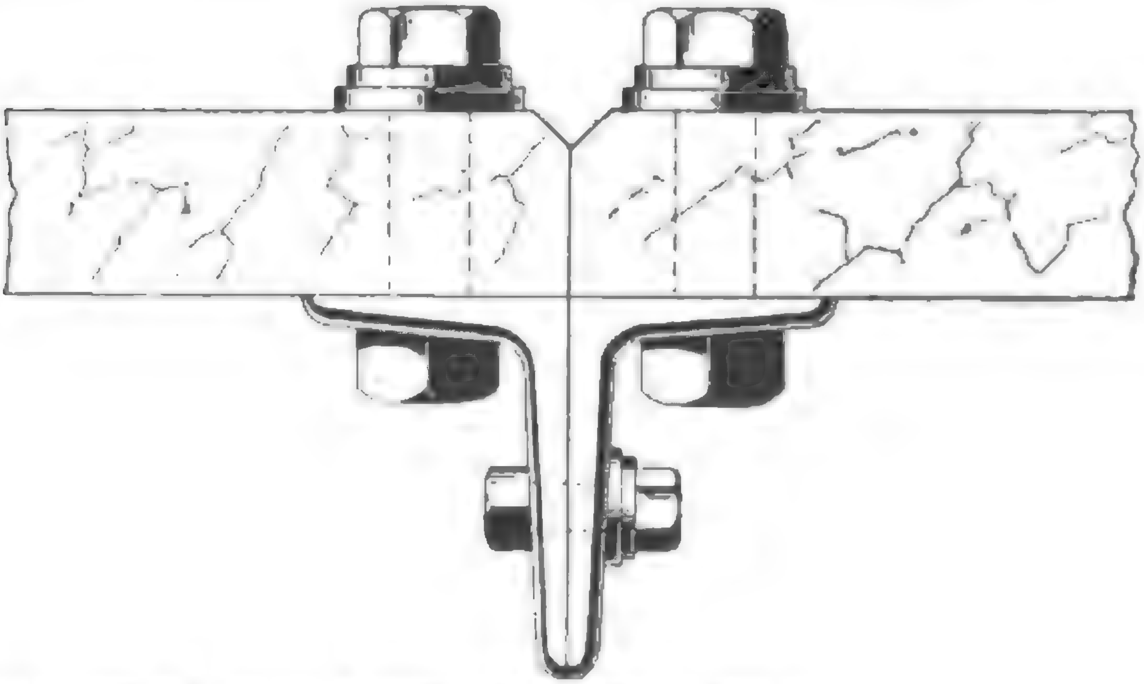


FIG. 2,819.—Method of joining adjacent switchboard panels.

Switchboards.—The plan of switchboard wiring for alternating current work depends upon the system in use and thi latter may be either of the single phase, two phase, three phase, or monocyclic types. The general principles in all these cases, however, are practically identical.

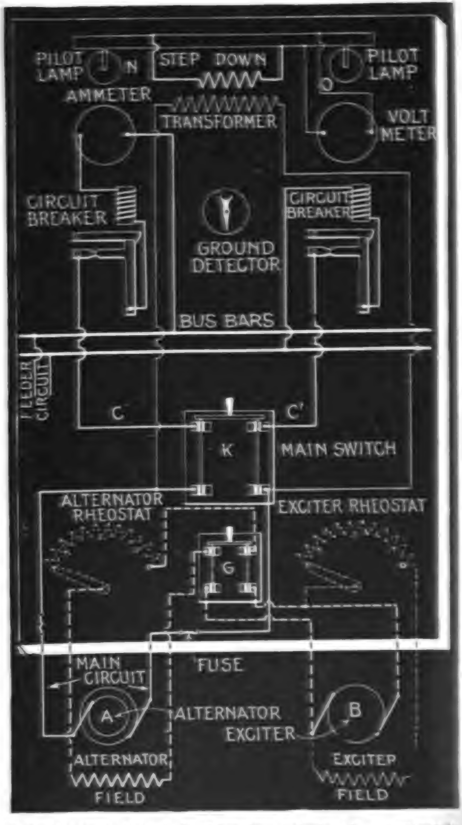
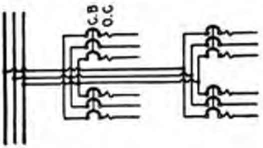
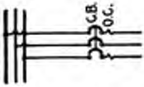

PILOT LAMP
N
STEP DOWN
TRANSFORMER
PILOT LAMP
O
AMMETER
VOLT METER
CIRCUIT BREAKER
GROUND DETECTOR
CIRCUIT BREAKER
BUS BARS
FEEDER CIRCUIT
C
C'
K
MAIN SWITCH
ALTERNATOR RHEOSTAT
EXCITER RHEOSTAT
G
MAIN CIRCUIT
FUSE
A
ALTERNATOR
EXCITER
B
ALTERNATOR FIELD
EXCITER FIELD

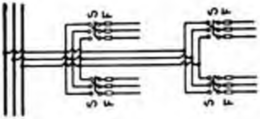
FIG. 2,820.—Switchboard wiring for a single phase separately excited alternator. The direct current circuits are represented by dotted lines, and the alternating current circuit, by solid lines.

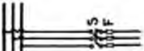
Fig. 2,820 shows the switchboard wiring for a single phase alternator. As an aid in reading the diagram, the conductors carrying alternating current are represented by solid lines, and those carrying direct current, by dotted lines.

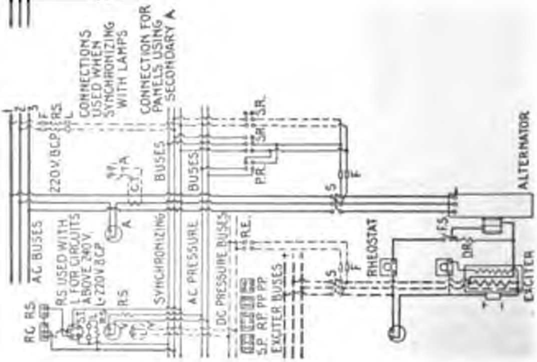
The exciter shown at the right is a shunt wound machine. By means of the exciter rheostat, the voltage for exciting the field winding of the alternator is varied; this, in turn, varies the voltage developed in the










CONNECTIONS USED WHEN SYNCHRONIZING WITH LAMPS
CONNECTION FOR PANELS USING SECONDARY A
1
2
3
F
RS
L
220 V. 8 C.P.
W.
A
C.T.
BUSES
BUSES
S.R.
SR
P.R.
S
F
ALTERNATOR
RC RS
RS USED WITH L FOR CIRCUITS ABOVE 240 V. L-220 V 8 C.P.
AC BUSES
A
ST
L
RS
RS
SYNCHRONIZING
AC PRESSURE
DC PRESSURE BUSES
R.E.
S.P. RP PP PP
EXCITER BUSES
S
F
RHEOSTAT
F.S.
DR
EXCITER

FIGS. 2,821 to 2,825.—General Electric diagrams of connections. A, ammeter; C.B, circuit breaker; C.P, candle power; C.T, current transformer; D.R, discharge resistance; F, fuse; F.S, field switch; L, lamp; O.C, overload coil; P.P, pressure plug; P.R, pressure receptacle; R.C, reactance; rheo, rheostat; R.P, synchronizing plug, running; R.S, resistance; S, switch; S.I, synchronism indicator; S. P, synchronizing plug, starting; S.R, synchronizing receptacle; V, voltmeter.

alternator since the main leads of the exciter are connected through a double pole switch G to the field winding of the alternator.

A rheostat is also introduced in the alterantor field winding circuit to adjust the alternator pressure. It may seem unnecessary to employ a rheostat in each of two separate field circuits to regulate the voltage of the alternator, but these rheostats are not both used to produce the same result. When a considerable variation of pressure is required, the exciter rheostat is manipulated, whereas for a fine adjustment of voltage the alternator rheostat is preferably employed.

Sometimes a direct current ammeter is introduced in the alternator's field circuit to aid in the adjustment.

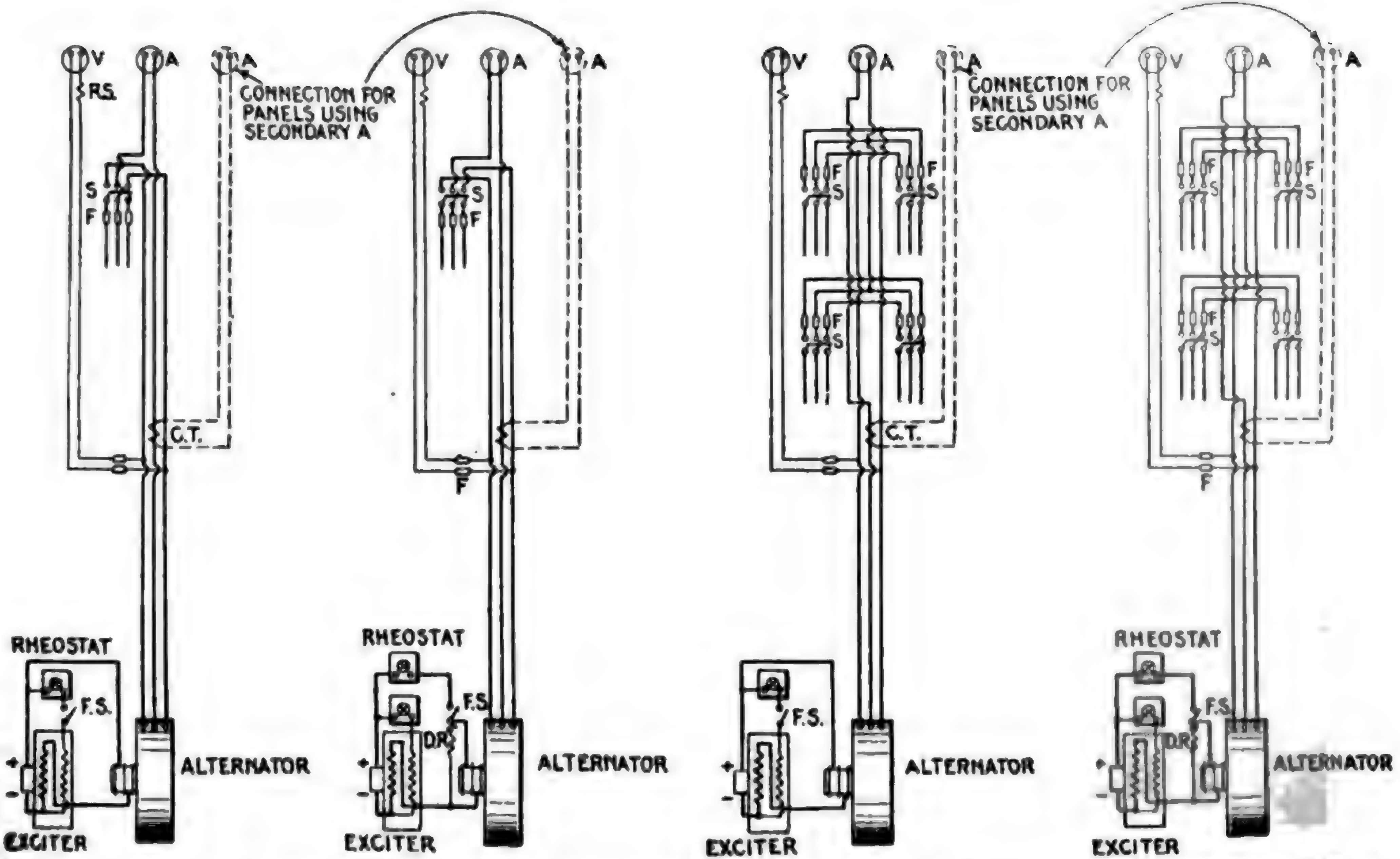
The main circuit of alternator after being protected on both sides by fuses, runs to the double pole switch K. These fuses serve as a protection to the alternator in case of a short circuit at the main switch. It will be noticed the fuses are of the single pole type and are mounted a considerable distance apart; this is to prevent any liability of a short circuit between them in case of action. Enclosed fuses are now used entirely for such work, since in these there is no danger of heated metal being thrown about and causing damage when the fuse wire is melted. Enclosed fuses are also more readily and quickly replaced than open fuses, the containing tube of each being easy to adjust in circuit, and when the fuse wire within is once melted the tube is discarded for a new one.

The main circuit after passing through the main switch is further protected on both sides by circuit breakers. Leaving these protective devices, the left hand side of the circuit includes the alternating current ammeter, and then connects with one of the bus bars. The right hand side of the circuit runs from the circuit breaker to the other bus bar. As many feeder circuits may be connected to the bus bars and supplied with current by the alternator as the capacity of this machine will permit. If, however, there be more than one feeder circuit, each must be wired through a double pole switch.

In alternating current work the pressures dealt with are much greater than those in direct current installations, so that proportionate care must be taken in the wiring to remove all possibility of grounds.

To locate such troubles, however, should they occur, a ground detector is provided. For this class of work the ground detector must be an instrument especially designed for high pressure circuits. Two of its terminals should be connected to the line wires and the third, to ground; in case of a leak on the line, a current will then flow through the detector and by the position of the pointer the location and seriousness of the leak may be judged.

A step down transformer is also rendered necessary for the voltmeter and the pilot lamps, owing to the high voltage in use. The primary winding of the transformer is connected across the main circuit of the alternator. This connection should never be made so that it will be cut out of circuit when the main switch is open, for it is always advisable to consult the voltmeter before throwing on the load by closing this switch.


V
A
A
R.S.
CONNECTION FOR PANELS USING SECONDARY A
S
F
C.T.
F
F.S.
D.R.
RHEOSTAT
ALTERNATOR
EXCITER
+
-

Figs. 2,826 to 2,829.—General Electric diagrams of connections. A, ammeter; C.B, circuit breaker; C.P, candle power; C.T, current transformer; D.R, discharge resistance; F, fuse; F.S, field switch; L, lamp; O.C, overload coil; P.P, pressure plug; P.R, pressure receptacle; R C, reactance; rheo, rheostat; R P, synchronising plug, running; R.S, resistance; S, switch; S I, synchronous indicator; S P, synchronising plug, starting; S.R, synchronising receptacle; V, voltmeter.

Ques. How does the switchboard wiring for a two phase system differ from the single phase arrangement shown in fig. 2,820?

Ans. It is practically the same, except for the introduction of an extra ammeter and a compensator in each of the outside wires, and in the use of a four pole switch in place of the two pole main switch.

The ammeters, of course, are for measuring the alternating currents in each of the two phases or legs of the system, and the compensators are two transformers with their primary coils in series with the outside wires and their secondary coils in series with each other across the outside wires. The transformers thus connected are known as compensators or pressure regulators, and as such compensate for the drop in pressure on either side of the system.

Ques. How is the four pole main switch wired?

Ans. Its two central terminals which connect directly with the line wires, are joined together by a conductor, and from this point one wire is led off. This wire, together with the two outside wires, form the feeders of the system.

Ques. How many voltmeters are required for the two phase system?

Ans. One voltmeter is sufficient on the board if a proper switching device be employed to shift its connections across either of the two circuits; otherwise, two voltmeters will be necessary, one bridged across each of these respective circuits.

The same reasoning holds true in regard to ground detectors, so that one or two of these will be required, depending upon the aforementioned conditions.

Ques. What are the essential points of difference between the single phase switchboard wiring as shown in fig. 2,820, and that required for a three wire three phase system?

Ans. The three phase system requires the use of a three pole switch in place of the two pole switch; the insertion of an ammeter, a circuit breaker, and a compensator in each of the thre wires of the system; the presence of two ground detectors instead of one, and the addition of a voltmeter switch if but on voltmeter be provided, or else the installation of two voltmeters connected the one between the middle wire and outer right hand wire, and the other between the middle wire and outer lef hand wire.

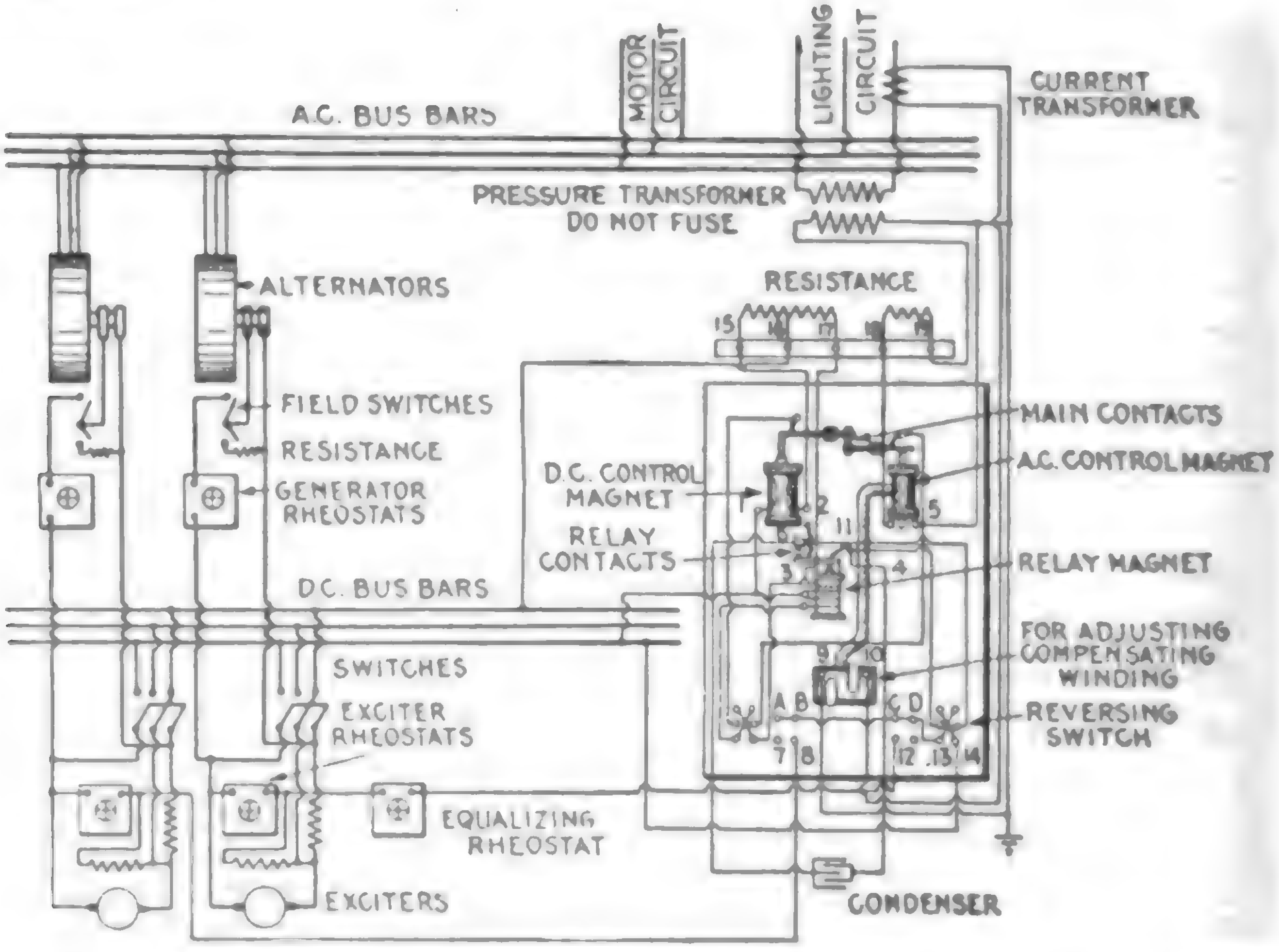
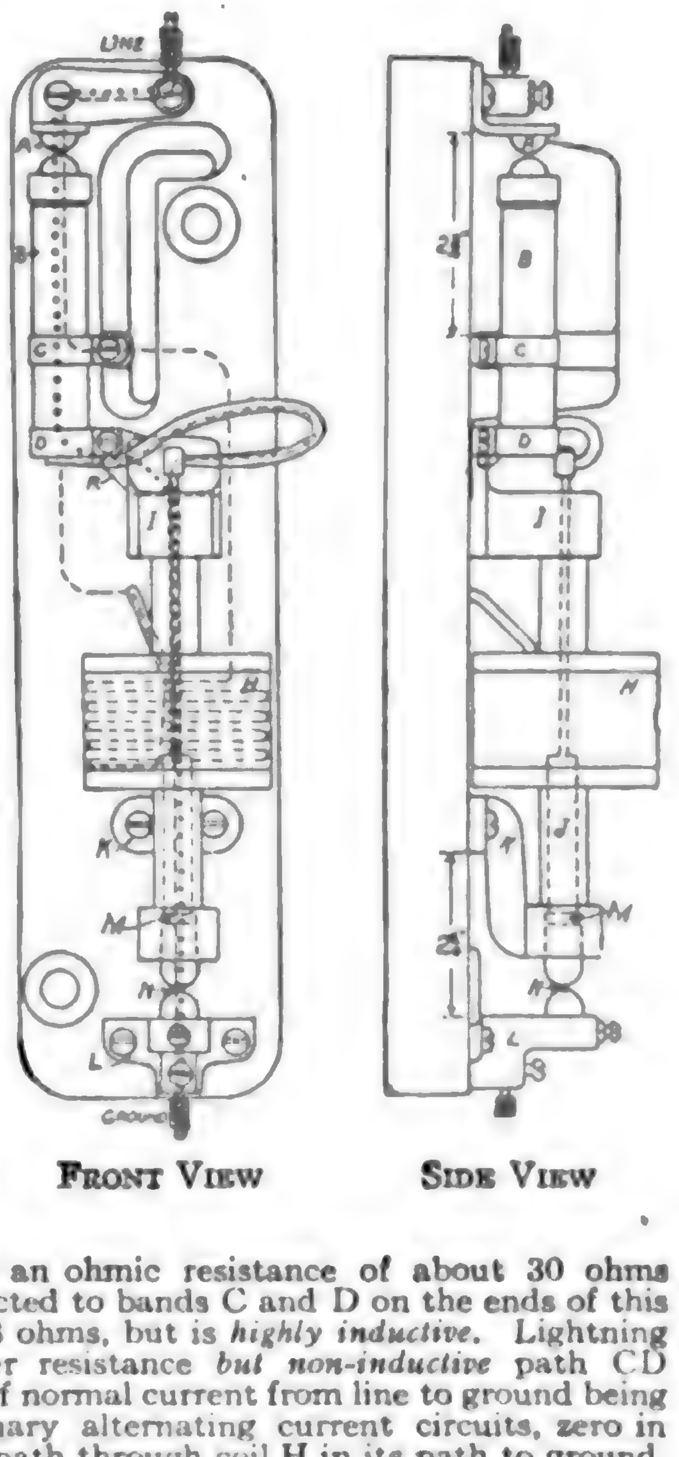

MOTOR CIRCUIT
LIGHTING CIRCUIT
CURRENT TRANSFORMER
A.C. BUS BARS
PRESSURE TRANSFORMER DO NOT FUSE
ALTERNATORS
RESISTANCE
15
16
17
18
19
FIELD SWITCHES
RESISTANCE
GENERATOR RHEOSTATS
MAIN CONTACTS
A.C. CONTROL MAGNET
D.C. CONTROL MAGNET
1
2
11
5
RELAY CONTACTS
3
4
RELAY MAGNET
D.C. BUS BARS
FOR ADJUSTING COMPENSATING WINDING
9
10
SWITCHES
A
B
C
D
REVERSING SWITCH
EXCITER RHEOSTATS
7
8
12
13
14
EQUALIZING RHEOSTAT
EXCITERS
CONDENSER

FIG. 2,830.—Diagram of switchboard connections for General Electric automatic voltag regulator with two exciters and two alternators.

Ques. Mention a few points relating to lightning arresters.

Ans. In most cases where direct current is used they are mounted on the walls of the station near the place at which the line wires enter. If they be mounted outside the station at this point, special precautions should be taken to keep them free



FRONT VIEW **SIDE VIEW**

FIGS. 2,831 and 2,832.—Garton-Daniels alternating current lightning arrester; diagram showing connections. A lightning discharge takes the path indicated by the dotted line, across the upper air gap A, through resistance rod B, C, D, across copper strip R on the base, thence flowing to ground through the movable plunger M, lower on gap N, and ground binding post L. The discharge path is practically straight, contains an air gap, distance of but 3-32 inch, a series resistance averaging but 225 ohms. The lightning discharge does not flow through the flexible lead connecting band D on the lower end of the resistance rod with the top of the movable plunger. These two points are electrically connected by the heavy copper strip R, and lightning discharges generally, if not always, take the path across this copper strip in preference to flowing through the inductance of the one turn of flexible cable. When a discharge occurs from line to ground through any lightning arrester, the air gaps arc over, and so there is offered a path from line to ground for the line current. This flow of line current following the lightning discharge to ground may vary anywhere from a small capacity current where the arrester is installed on an ungrounded circuit, a moderately heavy flow on a partially grounded circuit, to a very heavy flow on a grounded circuit—either a circuit operated as a dead grounded circuit, or a circuit which has become accidentally grounded during a storm. The path taken by this flow of line current from line to ground may be traced by following the path shown by the dashed line. It, as seen, crosses upper air gap A, flows through section B of the resistance rod to band C. Leaving band C it flows through the magnet winding H, thence to band D on the resistance rod, through flexible lead to upper end of movable plunger, through movable plunger, across lower air gap N, to ground binding post L, thence to ground. The function of the short length of resistance rod CD is as follows: It has an ohmic resistance of about 30 ohms but is *non-inductive*. Magnet winding H, connected to bands C and D on the ends of this short length of rod has an ohmic resistance of 3 ohms, but is *highly inductive*. Lightning discharges being of *high frequency* take the higher resistance *but non-inductive* path CD in their passage from line to ground. The flow of normal current from line to ground being of a very low frequency, 25 or 60 cycles in ordinary alternating current circuits, zero in direct current circuits—takes the *low resistance* path through coil H in its path to ground. Section CD of the rod is used therefore simply to shunt the inductance of winding H to high frequency lightning discharges, leaving the lightning discharge path in the arrester a *non-inductive* highly efficient path. In all Garton-Daniels A. C. lightning arresters operating on non-grounded or partially grounded circuits, the action of the air gaps and series resistance are together sufficient to extinguish the flow of normal current to ground at the zero point of the generator voltage wave. If, however, as frequently happens, the line grounds accidentally during a storm, then the arrester does not have to depend for its proper operation on the arc extinguishing properties of the air gaps and resistance, but the heavier flow of line current through the arrester energizes the movable plunger, which raises upward in the coil, opening the circuit between the discharge point M and the lower end of the plunger. To limit the flow of line current to ground the resistance rod B is provided, there being approximately 225 ohms between the discharge point A and clamp C in the 2,500 volt arrester. This feature is particularly effective where the circuit is temporarily or accidentally grounded. The series resistance prevents a heavy short circuit through the arrester and limits the current to a value that is readily broken by the cut out and is not enough to impede the passage of the discharge.

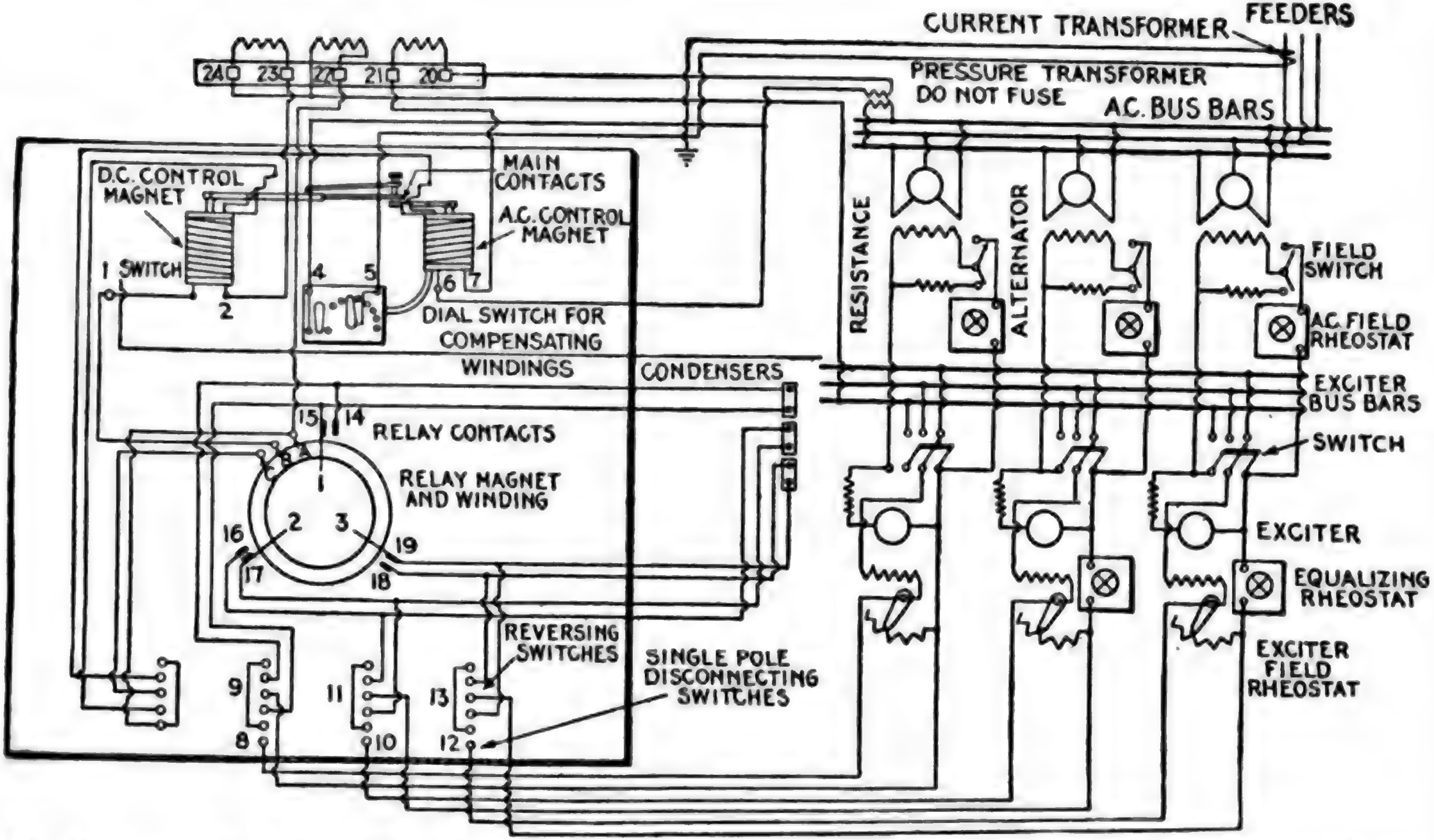

CURRENT TRANSFORMER
FEEDERS
PRESSURE TRANSFORMER DO NOT FUSE
A.C. BUS BARS
24
23
22
21
20
D.C. CONTROL MAGNET
MAIN CONTACTS
A.C. CONTROL MAGNET
1 SWITCH
2
4
5
6
7
DIAL SWITCH FOR COMPENSATING WINDINGS
RESISTANCE
ALTERNATOR
FIELD SWITCH
A.C. FIELD RHEOSTAT
CONDENSERS
EXCITER BUS BARS
15
14
RELAY CONTACTS
RELAY MAGNET AND WINDING
1
2
3
16
17
18
19
SWITCH
EXCITER
EQUALIZING RHEOSTAT
EXCITER FIELD RHEOSTAT
REVERSING SWITCHES
SINGLE POLE DISCONNECTING SWITCHES
9
8
11
10
13
12

FIG. 2,833.—Diagram of switchboard connections for General Electric automatic voltage regulator with three exciters and three alternators.

from moisture by enclosing them in iron cases, but no matter where they are located it is necessary that they be dry in order to work properly.

If possible, one place should be set aside for them and a marble or slate panel provided on which they may be mounted.

Wooden supports are undesirable for lightning arresters on account of the fire risk incurred; this, however, may be reduced to a minimum by employing skeleton boards and using sheets of asbestos between the arresters and the wood.

In parts of the country where lightning is of common occurrence and where overhead circuits are installed which carry high pressures, heavy currents, and extend over considerable territory, it is advisable to have the station well equipped with lightning arresters of the most improved types.

In each side of the main circuit, between the lightning arrester connections and the switchboard apparatus there should be connected a choke coil or else each of the main conductors at this point should be tightly coiled up part of its length to answer the same purpose.

A quick and effective way of coiling up a wire consists in wrapping around a cylindrical piece of iron or wood that part of the conductor in which it is desired to have the coils, the desired number of times, and then withdrawing the cylindrical piece. The coils, each of which may contain 50 or 200 turns, thus inserted in the main circuit introduce a high resistance or reluctance to a lightning current, and thus prevent it passing to the generator; there will, however, be an easy path to earth afforded it through the lightning arrester, and so no damage will be done. Coils of the nature just mentioned may advantageously be introduced between the generator and switchboard to take up the reactive current developed upon the opening of the circuit, and in the case of suspended conductors, the coils may be used to take up the slack by the spring-like effect produced by them.

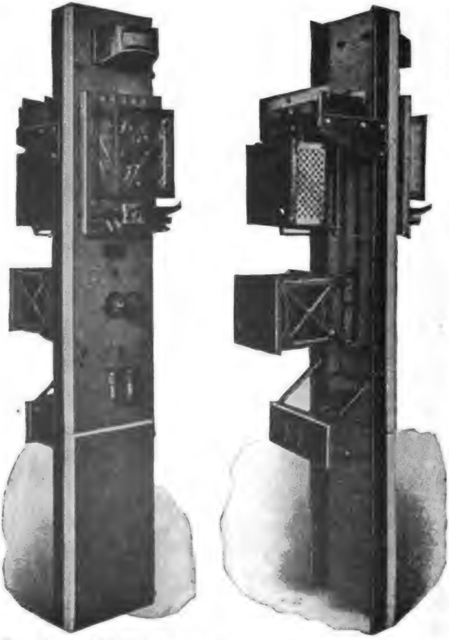
The safety of the operator should be especially considered in the design of high pressure alternating current switchboards.

Such protection may be secured by screening all the exposed terminals, or preferably by mounting all the switch mechanism on the back of the board with simply the switch handle projecting through to the front; by pushing or pulling the switch handle, the connections can thus be shifted either to one side of the system or to the other.

Ques. Upon what does the work of assembling a switchboard depend?

Ans. It depends almost entirely upon the size of the plant, varying from the simple task of mounting a single panel in the case of an isolated plant, to the more difficult problem of supporting a large number of panels in a central station.

Ques. When the material chosen for a switchboard must be shipped a considerable distance, what form of board should be used?



FIGS. 2,834 and 2,835.—Front and rear views showing General Electric automatic voltage regulator mounted on switchboard

Ans. The board units or "slabs" should be of small dimensions, to avoid the liability of breakage and expense of renewal when a unit becomes cracked or machine injured.

Ordinarily, switchboards vary from five to eight feet in height and the widths of the panels vary from five to six feet. In some boards the seams between the slabs run vertically, and in others horizontally. In order to render the assembling of the switchboard as simple as possible, and its appearance when finished the most artistic, these seams should run horizontally rather than vertically. The edges of each of the slabs should also be chamfered so that there will be less danger of their breaking out when being mounted on the framework.

Ques. In assembling a swtichboard, how should the lower slabs be placed, and why?

Ans. They should be suspended a little distance from the floor to prevent contact with any oil, dirt, water or rubbish that might be on the floor.

Ques. How are the slabs or panels supported?

Ans. They are carried on an iron or wooden framework with braces to give stability.

The braces should be securely fastened at one end to the wall of the station, and at the other end to the framework of the board, as shown in fig. 2,836.

To fasten the switchboard end of the brace directly to the slate, marble or other material composing the board is poor practice and should never be attempted.

If the station be constructed of iron, these switchboard braces must be such that they will thoroughly insulate the board and its contents from the adjoining wall.

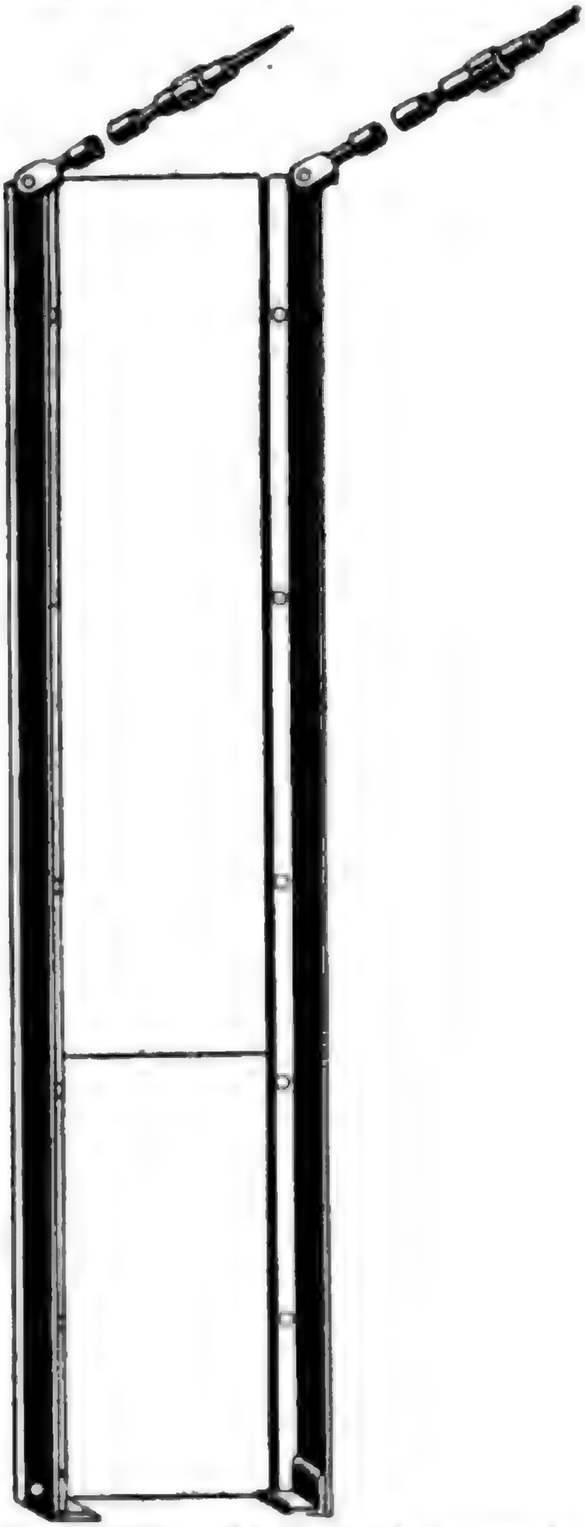


Fig. 2,836.—Method of supporting the framework of a switchboard.

Ques. What is the usual equipment of a switchboard?

Ans. It comprises switching devices, current or pressure limiting devices, indicating devices, and fuses for protecting the apparatus and circuits.

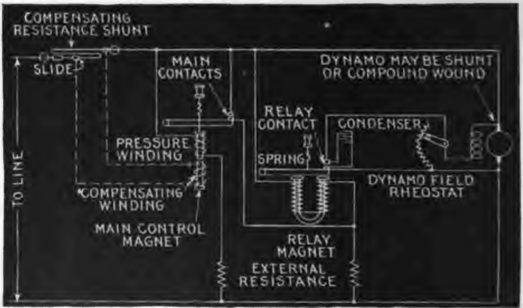


FIG. 2,837.—Diagram showing elementary connections of General Electric automatic regulator for direct current. It consists essentially of a main control magnet with two independent windings and a differentially wound relay magnet. One winding, known as the pressure winding, of the main control magnet is connected across the dynamo terminals, the other across a shunt in one of the load mains. The latter is the "compensating winding" and it opposes the action of the pressure winding so that as the load increases, a higher pressure at the dynamo is necessary to "over compound" for line drop. In ordinary practice, the voltage terminals are connected to the bus bars, and the compensating shunt inserted in one of the principal feeders of the system. In operation the shunt circuit across the dynamo field rheostat is first opened by means of a switch provided for that purpose on the base of the regulator and the rheostat turned to a point that will reduce the generator voltage 35 per cent below normal. The main control magnet is at once weakened and allows the spring to pull out the movable core until the main contacts are closed. This closes the second circuit of the differential relay, thus neutralizing its windings. The relay spring then lifts the armature and closes the relay contacts. The switch in the shunt circuit across the dynamo field rheostat is now closed, practically short circuiting the rheostat, and the dynamo voltage at once rises. As soon as it reaches the point for which the regulator has been adjusted, the main control magnet is strengthened, which causes the main contacts to open, which in turn open the relay contacts across the rheostat. The rheostat is now in the field circuit, the voltage at once falls off, the main contacts are closed, and relay armature released, and shunt circuit across the rheostat again completed. The voltage then starts to rise and this cycle of operation is continued at a high rate of vibration, maintaining not a constant but a steady voltage at the bus bars. When neither the compensating winding nor pressure wires are used, there will be no "over compounding" effect due to increase of load and a constant voltage will be maintained at the bus bars. The compensating winding on the control magnet, which opposes the pressure winding is connected across an adjustable shunt in the principal feeder circuit. As the load increases the voltage drop across the shunt increases and the effect of the compensating winding becomes greater. This will require a higher voltage on the pressure winding to open the main contacts and the regulator will therefore cause the dynamo to compensate for line drop, maintaining at the bus bars a steady voltage without fluctuations, which rises and falls with a load on the feeders, giving a constant voltage at the lamps or center of distribution. The compensating shunt may be adjusted so as to compensate for any desired line drop up to 15 per cent; it is preferably placed in the principal lighting feeder, but may be connected to the bus bars so that the total current will pass through it. The latter method, however, is sometimes desirable, as large fluctuating power loads on separate feeders might disturb the regulation of the lighting feeders. Adjustment is made by sliding the movable contact at the center of the shunt. This contact may be clamped at any desired point and determines the pressure across the compensating winding of the regulator's main control magnet. Where pressure wires are run back to the central station from the center of distribution they may be connected directly to the pressure winding of the main control magnet, and it is unnecessary to use the compensating shunt. The pressure wires take the place of the leads from the control magnet to the bus bars and maintain a constant voltage at the center of distribution.

On some switchboards are also mounted small transformers for raising or lowering the voltages, and lightning arresters as a protection from lightning. In addition to the apparatus previously mentioned nearly all switchboards carry at or near their top two or more incandescent lamps provided with shades or reflectors, for lighting the board.

Ques. What should be done before wiring a switchboard?

Ans. The electrical connections between the various apparatus mounted on the face or front of the board, are made on the back of the board. It is necessary that these connections be properly made else considerable electrical power will be

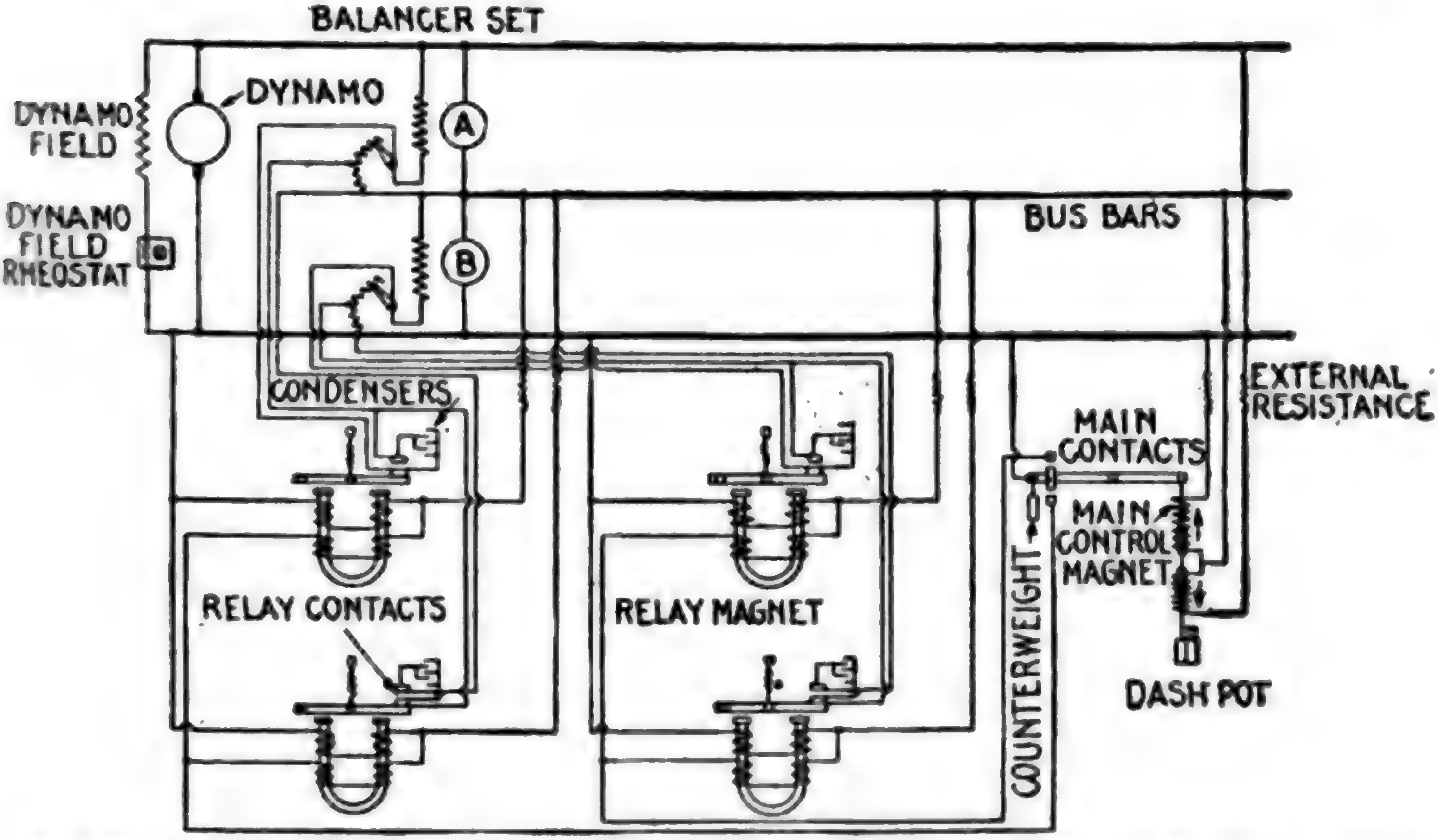

BALANCER SET
DYNAMO
DYNAMO FIELD
DYNAMO FIELD RHEOSTAT
A
B
BUS BARS
CONDENSERS
EXTERNAL RESISTANCE
MAIN CONTACTS
MAIN CONTROL MAGNET
RELAY CONTACTS
RELAY MAGNET
COUNTERWEIGHT
DASH POT

FIG. 2,838.—Diagram showing connections of General Electric automatic voltage regulator for direct current as connected for maintaining balanced voltage on both sides of a three wire system using a balancer set. In operation, should the voltage on the upper bus bars become greater than that on the lower ones, the middle and upper contacts on the regulator will close, thus opening the relay contacts to the left and closing those to the right. This inserts all the resistance in the field of balancer A, and short circuits the resistance in the field of balancer B. A will then be running as a motor, and B as a dynamo, thereby equalizing the two voltages until that on the lower bus bars becomes greater than that of the upper ones; then the regulator contacts operate in the opposite direction and balancer A is run as a dynamo, and balancer B as a motor. This cycle of operation is repeated at the rate of from three to four hundred times per minute, thus maintaining a balanced voltage on the system.

wasted at this point. The wiring on the back of the board should therefore be planned out on paper before commencing the work.

In laying out the plan of wiring care must be taken to allow sufficient contact surface at each connection; there should be not less than one square inch of contact surface allowed for each 160 amperes of current transmitted.

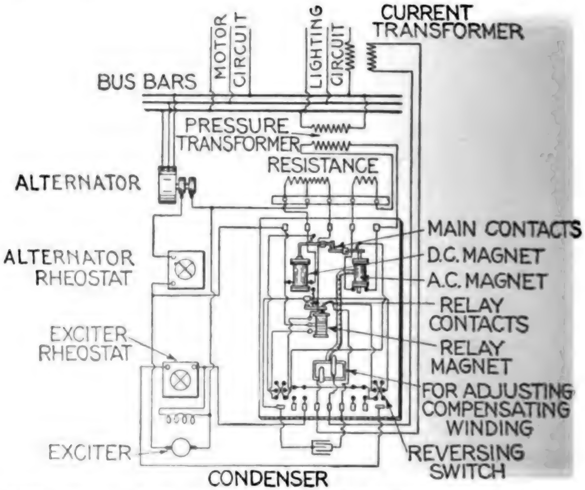

MOTOR CIRCUIT
LIGHTING CIRCUIT
CURRENT TRANSFORMER
BUS BARS
PRESSURE TRANSFORMER
RESISTANCE
ALTERNATOR
MAIN CONTACTS
D.C. MAGNET
A.C. MAGNET
ALTERNATOR RHEOSTAT
RELAY CONTACTS
EXCITER RHEOSTAT
RELAY MAGNET
FOR ADJUSTING COMPENSATING WINDING
EXCITER
REVERSING SWITCH
CONDENSER

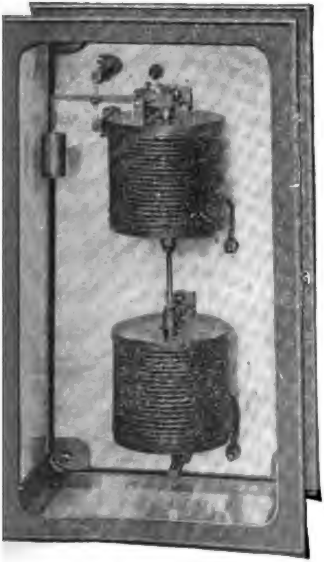
Fig. 2,839.—Diagram of connections of General Electric voltage regulators for one or more alternators using one exciter.

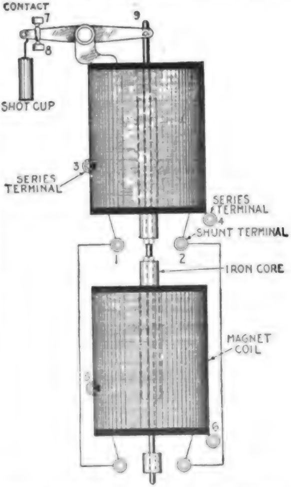
For the bus bars, which by the way are always of copper, one square inch per 1,000 amperes is the usual allowance; this is equal to 1,000 circular mils of cross sectional area per ampere.

Every effort should be made to give the bus bars the greatest amount of radiation consistent with other conditions, in order that their resistances may not become excessive owing to the heat developed by the large currents they are forced to carry. Suppose, for instance, the number of amperes to be generated is such as to require bus bars having each a cross sectional area of one square inch. If the end dimensions of these bars were each 1 inch by 1 inch, there would be less radiating surface than if their dimensions were each 2 inches by ½ inch.

Operation of Alternators.—The operation of an alterna- or when run singly differs but little from that for a dynamo.

As to the preliminaries, the exciter must first be started. This is done in the same way as for any shunt dynamo. At first only a small current should be sent through the field winding of the alternator; then, if the exciter operates satisfactorily and the field magnetism of the operator show up well, the load may gradually be thrown on until the normal current is carried, the same method of procedure being followed as in the similar case of a dynamo.





FIGS. 2,840 and 2,841.—General Electric equalizer regulator designed to equalize the load on two machines, and diagram of connections.

On loading an alternator, a noticeable drop in voltage occurs ross its terminals. This drop in voltage is caused in part by the demagnetization of the field magnets due to the armature current, and so depends in a measure upon the position and form of the pole pieces as well as upon those of the teeth in the armature core. The resistance of the armature winding also causes a drop in voltage under an increase of load.

Another cause which may be mentioned is the inductance of the armature winding, which is in turn due to the positions of the armature coils with respect to each other and also with respect to the field magnets.

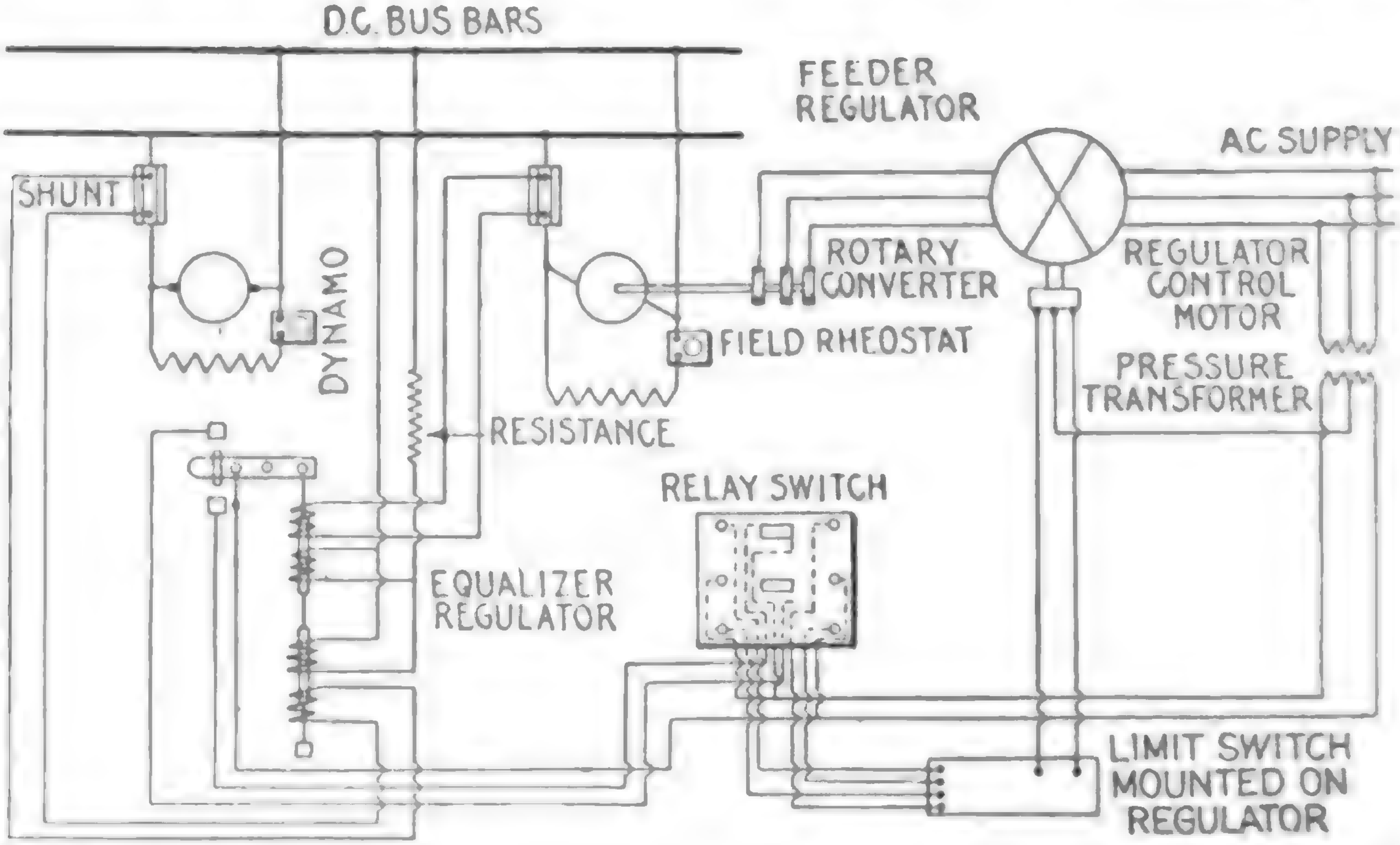

D.C. BUS BARS
FEEDER REGULATOR
AC SUPPLY
SHUNT
DYNAMO
ROTARY CONVERTER
REGULATOR CONTROL MOTOR
FIELD RHEOSTAT
PRESSURE TRANSFORMER
RESISTANCE
RELAY SWITCH
EQUALIZER REGULATOR
LIMIT SWITCH MOUNTED ON REGULATOR

FIG. 2,842.—Connection of General Electric equalizing regulator for equalizing loads on an engine driven dynamo and rotary converter running in parallel. Should the load on the dynamo become greater than that on the rotary converter, the middle and upper contacts on the regulator close, and thus by means of the relay switch and control motor, cause the feeder regulator to boost the voltage on the rotary until the loads again become equal. Should the load on the rotary converter become greater than that on the generator, the regulator contacts operate in the reverse direction and the feeder regulator is caused to buck the rotary voltage.

Alternators in Parallel.—When the load on a station increases beyond that which can conveniently be carried by one alternator, it becomes necessary to connect other alternators in parallel with it. To properly switch in a new machine in parallel with one already in operation and carrying load, requires a complete knowledge of the situation on the part of the attendant, and also some experience.

The connections for operating alternators in parallel are shown in fig. 2,843. In the illustration the alternator A is in operation and is supplying current to the bus bars. The alternator B is at rest. The main pole switch B′ by means of which this machine can be connected into circuit is therefore open.

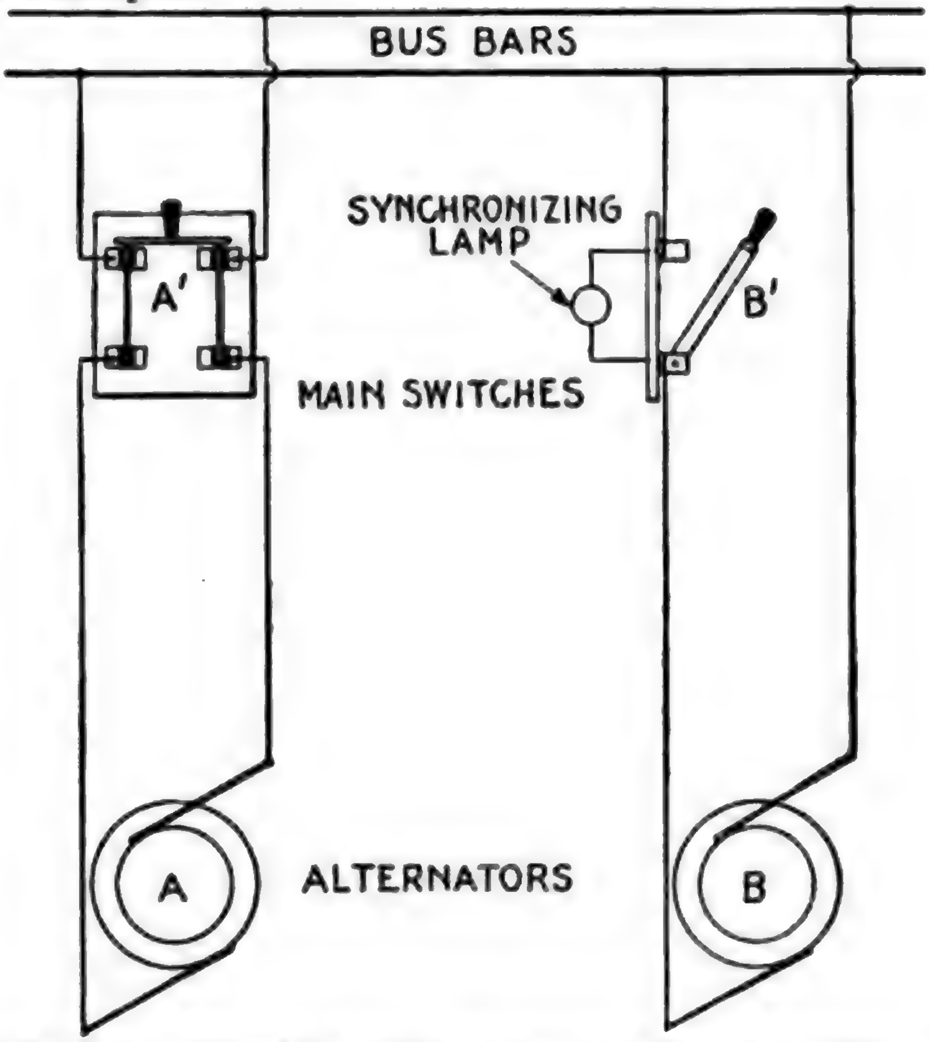


FIG. 2,843.—Method of synchronizing with one lamp; *dark lamp method.* Assuming A to be in operation, B, may be brought up to approximately the proper speed, and voltage. Then if B, be run a little slower or faster than A, the synchronizing lamp will glow for one moment and be dark the next. At the instant when the pressures are equal and the machines in phase, the lamp will become dark, but when the phases are in quadrature, the lamp will glow at its maximum brilliancy. Since the flickering of the lamp is dependent upon the difference in frequency, the machines should not be thrown in parallel while this flickering exists. The nearer alternator approaches synchronism, in adjusting its speed, the slower the flickering, and when the flickering becomes very slow, the incoming machine may be thrown in the moment the lamp is dark by closing the switch. The machines are then in phase and tend to remain so, since if one slow down, the other will drive it as a motor.

Now, if the load increase to such extent as to require the service of the second alterantor B, it must be switched in parallel with A. In order that both machines may operate properly in parallel, three conditions must be satisfied before they are connected together, or else the one alternator will be short circuited through the other, and serious results will undoubtedly follow.

Accordingly before closing main switch B, it is necessary that
1. The frequencies of both machines be the same;
2. The machines must be in synchronism;
3. The voltages must be the same.

Ques. How are the frequencies made the same?

Ans. By speeding up the alternator to be cut in, or change the speed of both until frequency of both machines is the same.

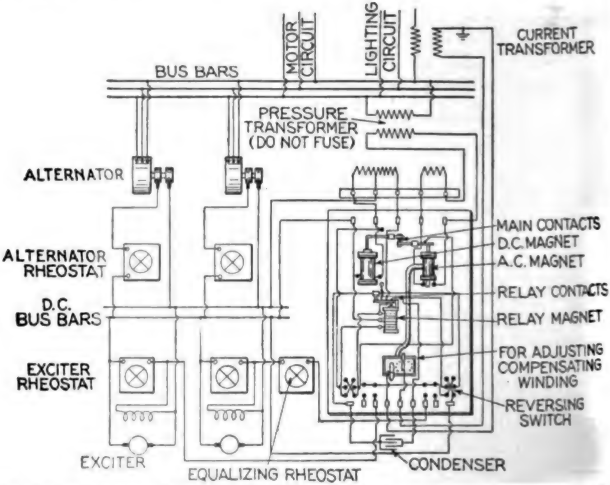

MOTOR CIRCUIT
LIGHTING CIRCUIT
CURRENT TRANSFORMER
BUS BARS
PRESSURE TRANSFORMER (DO NOT FUSE)
ALTERNATOR
ALTERNATOR RHEOSTAT
D.C. BUS BARS
EXCITER RHEOSTAT
EXCITER
EQUALIZING RHEOSTAT
MAIN CONTACTS
D.C. MAGNET
A.C. MAGNET
RELAY CONTACTS
RELAY MAGNET
FOR ADJUSTING COMPENSATING WINDING
REVERSING SWITCH
CONDENSER

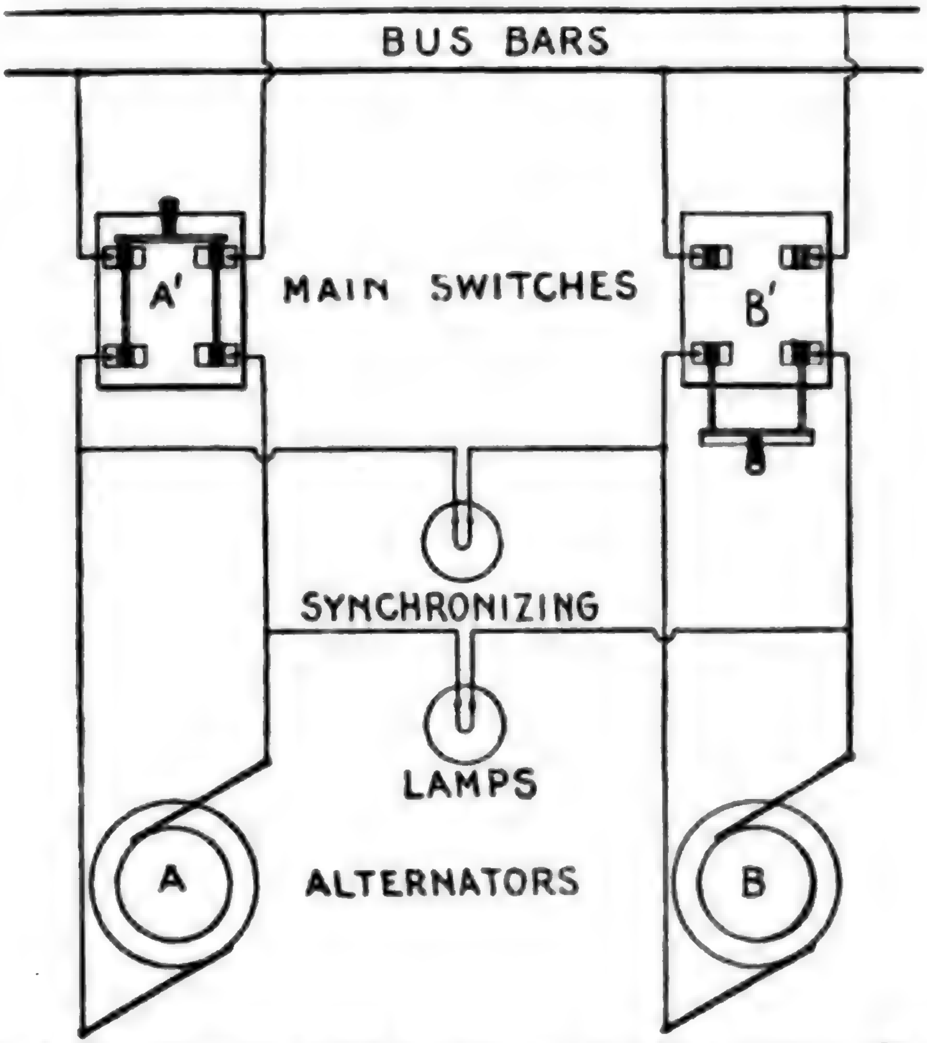
FIG. 2,844.—Diagram of connections of General Electric automatic voltage regulator for several alternators running in parallel with exciters in parallel.

Ques. How are the alternators synchronized or brought in phase?

Ans. The synchronism of the alternators is determined by employing some form of synchronizer, as by the single lamp method of fig. 2,843, or the two lamp method of fig. 2,845.

Ques. In synchronizing by the one lamp method, when hould the incoming machine be thrown in?

Ans. It is advisable to close the switch when the machines re approaching synchronism rather than when they are receding rom it, that is to say, the instant the lamp becomes dark.



IG. 2,845.—Method of synchronizing with two lamps; *dark lamp method*. The two synchronizing lamps are connected as shown, and each must be designed to supply its rated candle power at the normal voltage developed by the alternators. Now since the alternators are both running under normal field excitation the left hand terminals of each of them will alternately be positive and negative in polarity, while the right hand terminals are respectively negative and positive in polarity. If, however, the alternators be in phase with each other, the left hand terminals of both of them will be positive while the right hand terminals are negative, and when the left hand terminals of both machines are negative the right hand terminals will be positive. Hence, when the machines are in phase there will be no difference of pressure between the left hand terminals or between the right hand terminals of the two machines. Hence, if the synchronizing lamps be connected as shown, both will be dark. The instant there is a difference of phase, both lamps will glow attaining full candle power when the difference of phase has reached a maximum. As the alternators continue to come closer in step, the red glow will gradually fade away until the lamps become dark. Then the switch may be closed, thereby throwing the two machines in parallel. If the intervals between the successive lighting up of the lamps are of short duration it is advisable to wait until these become longer even though the other conditions are satisfied, because where the phases pass each other rapidly there is a greater possibility of not bringing them together at the proper instant. An interval of not less than five seconds should therefore be allowed between the successive lighting up of the lamps, before closing the switch.

Ques. What are the objections to the one lamp method?

Ans. The filament of the lamp may break, and caus

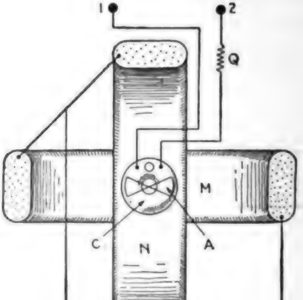


FIG. 2,846.—Inductor ty synchroscope. This ty is especially applicab where pressure tra formers are already in stalled for use with othe meters. As it require only about ten apparen watts it may be used o the same transforme with other meters. The are three stationary coi N, M and C, and a mo ing system, comprising a iron armature, A, rig attached to a sha suitably pivoted an mounted in bearings. pointer is also attach to the shaft. The mo ing system is balanc and is not subjected t any restraining force, su as a spring or gravit control. The axes of th coils N and M are in th same vertical plane, b 90 degrees apart, while th axis of C is in a horizont plane. The coils N and M are connected in "split phase" relation through an inductive resis ance P and non-inductive resistance Q, and these two circuits are parallel across the bus b terminals 3 and 4 of the synchroscope. Coil C is connected through a non-inductive re sistance across the upper machine terminals 1 and 2 of the synchroscope. **In operation** current in the coil C magnetizes the iron core carried by the shaft and the two projection marked A and "iron armature." There is however, no tendency to rotate the shaft. current be passed through one of the other coils, say M, a magnetic field will be produc parallel with its axis. This will act on the projections of the iron armature, causing it t turn so that the positive and negative projections assume their appropriate position i the field of the coil M. A reversal of the direction in both coils will obviously not affe the position of the armature, hence alternating current of the same frequency and pha in the coils C and M cause the same directional effect upon the armature as if direct curre were passed through the coils. If current lagging 90 degrees behind that in the coils and C be passed through the coil N, it will cause no rotative effect upon the armatur because the maximum value of the field which it produces will occur at the instant wh the pole strength of the armature is zero. The two currents in the coils M and N produ a shifting magnetic field which rotates about the shaft as an axis. As all currents ar assumed to be of the same frequency, the rate of rotation of this field is such that its dire tion corresponds with that of the armature projections at the instant when the poles in duced in them by the current in the coil C are at maximum value, and the field shif through 180 degrees in the same interval as is required for reversal of the poles. This the essential feature of the instrument, namely, that the armature projections take a position in the rotating magnetic field which corresponds to the direction of the field at th instant when the projections are magnetized to their maximum strength by their curre in the coil C. If the frequency of the currents in the coils which produce the shifting fiel be less than that in the coil which magnetized the armature, then the armature must tu in order that it may be parallel with the field when its poles are at maximum strength.

darkness, or the lamp may be dark with considerable voltage as it takes over 20 volts to cause a 100 volt lamp to glow.

Ques. What capacity of single lamp must be used?

Ans. It must be good for twice the voltage of either machine.

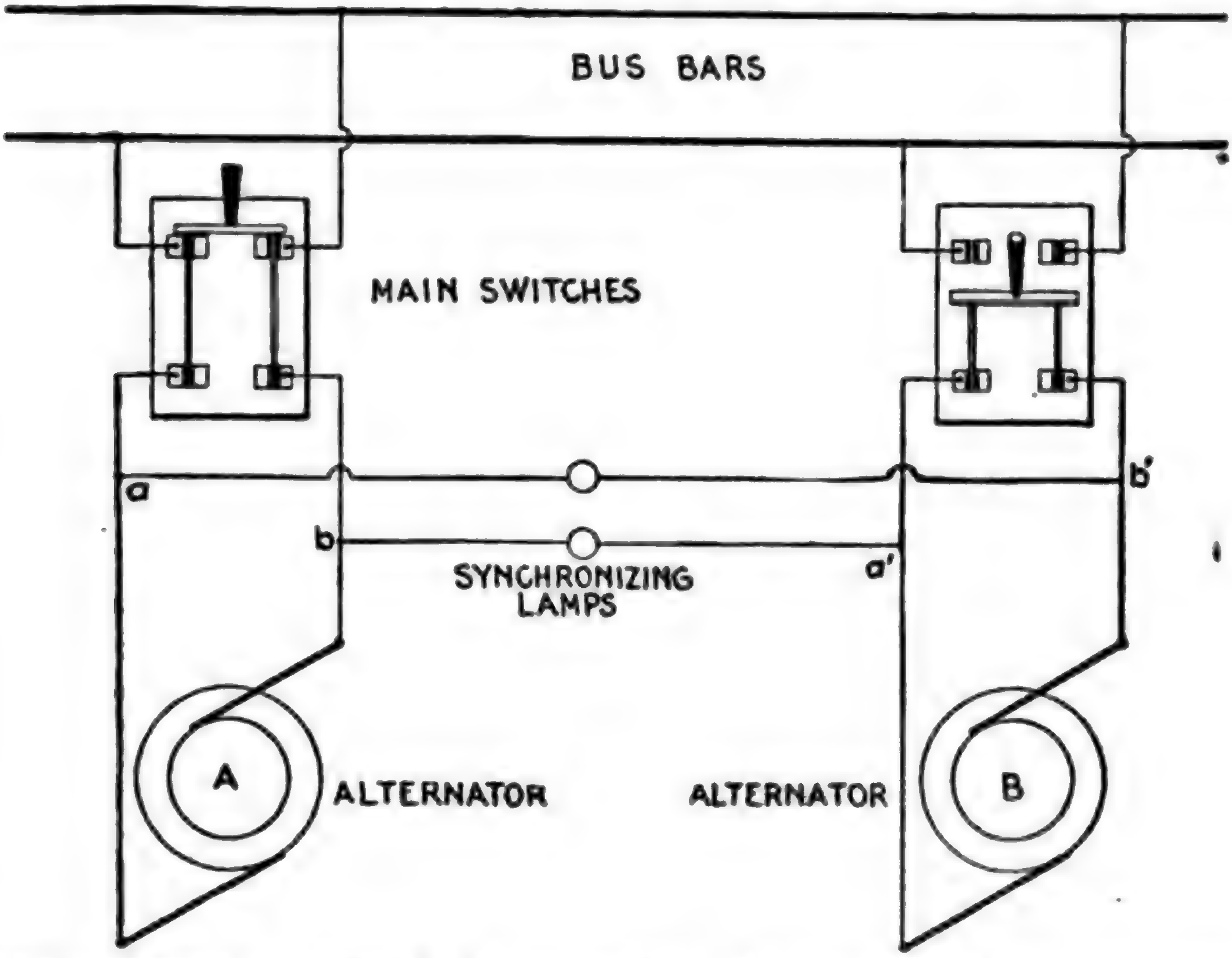


FIG. 2,847.—Brilliant lamp method of synchronizing. The synchronizing lamps are connected as shown, and must be of the alternator voltage. When the voltages are equal and the machines in phase, the difference of pressure between *a* and a given point is the same as that between *a'* and the same point; this obtains for *b* and *b'*. Accordingly, a lamp connected across *a b'* will burn with the same brilliancy as across *a' b*; the same holds for the other lamp. When the voltages are the same and the phase difference is 180° the lamps are dark, and as the phase difference is decreased, the lamps glow with increasing brightness until at synchronism they glow with maximum brilliancy. Hence the incoming alternator should be thrown in at the instant of maximum brilliancy.

Ques. What modification of the synchronizing methods shown in the accompanying illustrations is necessary when high pressure alternators are used?

Ans. Step down transformers must be used between the alternators and the lamps to obtain the proper working voltages for the lamps.

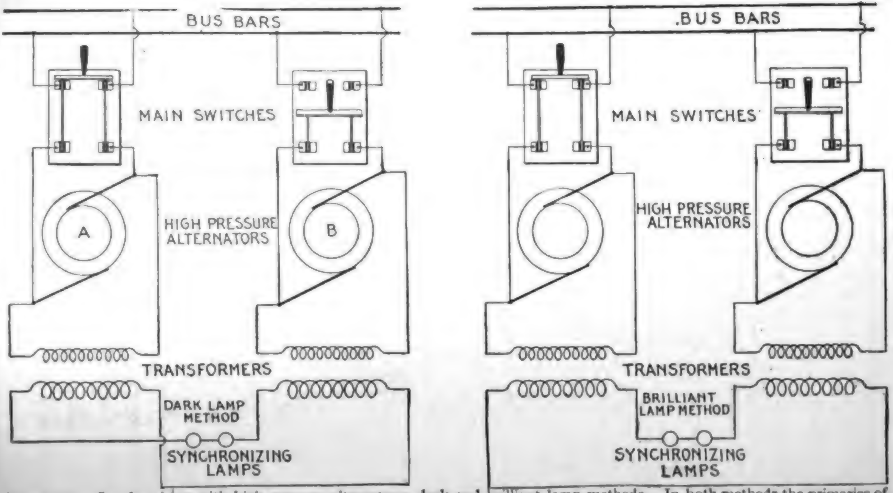

BUS BARS
MAIN SWITCHES
HIGH PRESSURE ALTERNATORS
A
B
TRANSFORMERS
DARK LAMP METHOD
SYNCHRONIZING LAMPS
BUS BARS
MAIN SWITCHES
HIGH PRESSURE ALTERNATORS
TRANSFORMERS
BRILLIANT LAMP METHOD
SYNCHRONIZING LAMPS

FIG. 2,848.—Synchronizing with high pressure alternators; dark and brilliant lamp methods. In both methods the primaries of the transformers are connected in the same way across the terminals of the alternators as shown. In the dark lamp method, the connections between the secondary coils of the transformers must be made so that when each is subjected to the same conditions the action of the one coil opposes that of the other as in the dark lamp method; then, if the transformers be both of the same design, there will be no voltage across the lamps when the alternators are in phase with each other. If the ratio of each transformer is such as to give, for example, 100 volts across its secondary terminals, then the two incandescent lamps since they are joined together in series must each be designed for 100 volts. One 200 volt lamp could be used in either method in place of the two 100 volt lamps. When, therefore, the alternators are directly opposite in phase to each other, both the lamps will burn brightly; as the alternators come together in phase the lamps will produce less and less light, until when the machines are exactly in phase no light will be emitted at all, at which instant the incoming alternator should be thrown in. It must be evident, if the transformer secondary connections are arranged as in the brilliant lamp method, so that they do not oppose each other, the lamps will be at maximum [illegible] the phase difference is 180°, assuming of course equalized voltage.

Ques. How is the voltage of an incoming machine adusted so that it will be the same as the one already in peration?

Ans. By varying the field excitation with a rheostat in the lternator field circuit.

Ques. How may two or more alternators be started imultaneously?

Ans. After bringing each of them up to its proper speed so s to obtain equal frequencies, the main switches may be closed, hereby joining their armature circuits in parallel. As yet, owever, their respective field windings have not been supplied ith current, so that no harm can result in doing this. The xciters of these machines after being joined in parallel, should hen be made to send direct current simultaneously through the eld windings of the alternators, and from this stage on the irections previously given may be followed in detail.

Ques. What are the conditions when two or more alterators are directly connected together?

Ans. If rigidly connected together, or directly connected to e same engine, they must necessarily run in the same manner t all times.

When machines connected in this way are once properly adjusted so that they are in phase with each other, their operation in parallel is even a simpler task than when they are all started together but are not directly connected.

Ques. When an alternator is driven by a gas engine, hat provision is sometimes made to insure successful peration in parallel?

Ans. An amortisseur winding is provided to counteract the ndency to "hunting."

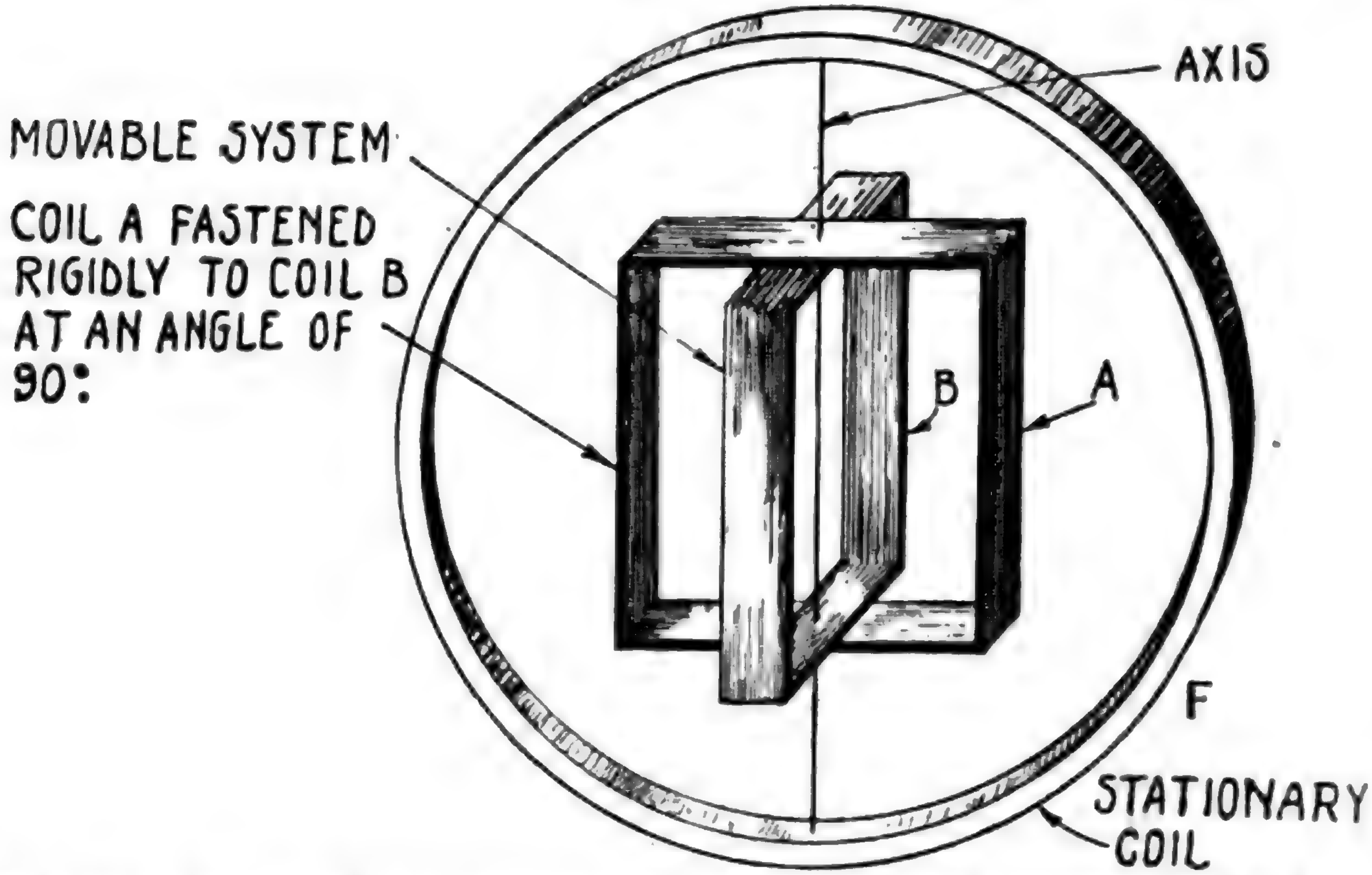


Fig. 2,849.—Diagram of Lincoln Synchronizer. **In construction,** a stationary coil F, has su pended within it a coil A, free to move about an axis in the planes of both coils and includin a diameter of each. If an alternating current be passed through both coils, A, will take position with its plane parallel to F. If now the currents in A and F be reversed wit respect to each other, coil A will take up a position 180° from its former position. Reversa of the relative directions of currents in A and F is equivalent to changing their phase rela tion by 180°, and therefore this change of 180° in phase relation is followed by a corre sponding change of 180° in their mechanical relation. Suppose now, instead of reversin the relative direction of currents in A and F, the change in phase relation between them b made gradually and without disturbing the current strength in either coil. It is eviden that when the phase difference between A and F reaches 90°, the force between A and will become reduced to zero, and a movable system, of which A may be made a part, is i condition to take up any position demanded by any other force. Let a second number o this movable system consist of coil B, which may be fastened rigidly to coil A, with it plane 90° from that of coil A, and the axis of A passing through diameter of B. Furthe suppose a current to circulate through B, whose difference in phase relation to that in A is always 90°. It is evident under these conditions that when the difference in phas between A and F is 90°, the movable system will take up a position, such that B is parall to F, because the force between A and F is zero, and the force between B and F is a maxi mum; similarly when the difference in phase between B and F is 90°, A will be parallel t F. That is, beginning with a phase difference between A and F of zero a phase change o 90° will be followed by a mechanical change on a movable system of 90°, and each successiv change of 90° in phase will be followed by a corresponding mechanical change of 90°. Fo intermediate phase relation, it can be proved that under certain conditions the positio of equilibrium assumed by the movable element will exactly represent the phase relations That is, with proper design, the mechanical angle between the plane of F and that of A and also between the plane of F and that of B, is always equal to the phase angle betwee the current flowing in F and those in A and B respectively. **As commercially constructe** coil F consists of a small laminated iron field magnet with a winding whose terminals ar connected with binding posts. The coils A and B are windings practically 90° apart on a laminated iron armature pivoted between the poles of the magnet. These two windings ar joined, and a tap from the junction is brought out through a slip ring to one of two othe binding posts. The two remaining ends are brought out through two more slip rings, on of which is connected to the remaining binding post, through a non-inductive resistance, an the other to the same binding post through an inductive resistance. A light aluminum **hand attached to the armature shaft marks the position assumed by the armature.**

Ques. What is the action of the amortisseur winding?

Ans. Any sudden change in the speed of the field, generates a current in the amortisseur winding which resists the change of velocity that caused the current.

The appearance of an amortisseur winding is shown in the cut below (fig. 2,850) illustrating the field of a synchronous condenser equipped with amortisseur winding.

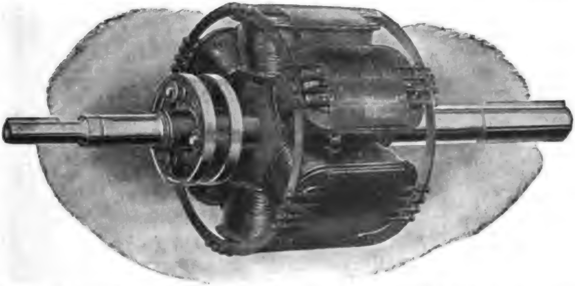


FIG. 2,850.—General Electric field of synchronous condenser provided with amortisseur winding. Hunting is accompanied by a shifting of flux across the face of the pole pieces due to the variation in the effect of armature reaction on the main field flux as the current varies and the angular displacement between the field and armature poles is changed. Copper short circuited collars placed around the pole face have currents induced in them by this shifting flux, which have such a direction as to exert a torque tending to oppose any change in the relative position of the field and armature. This action is similar to that of the running torque of an induction motor and the damping device has been still further developed until in its best form it resembles the armature winding of a "squirrel cage" induction motor. The pole pieces are in ducts, and low resistance copper bars placed in them with their ends joined by means of a continuous short circuiting ring extending around the field. Such a device has proven very effective in damping out oscillations started from any cause, the same winding doing duty as a damping device and to assist the starting characteristics.

Ques. How are three phase alternators synchronized?

Ans. In a manner similar to the single phase method.

Thus the synchronizing lamps may be arranged as in fig. 2,581, which is simply an extension of the single phase method.

Ques. Are three lamps necessary?

Ans. Only to insure that the connections are properly made, after which one lamp is all that is required.

Ques. How is it known that the connections of fig. 2,851 are correct?

Ans. If, in operation, the three lamps become bright or dark *simultaneously*, the connections are correct; if, this action take place *successively*, the connections are wrong.

If wrong, transpose the leads of one machine until simultaneous action of the lamps is secured.

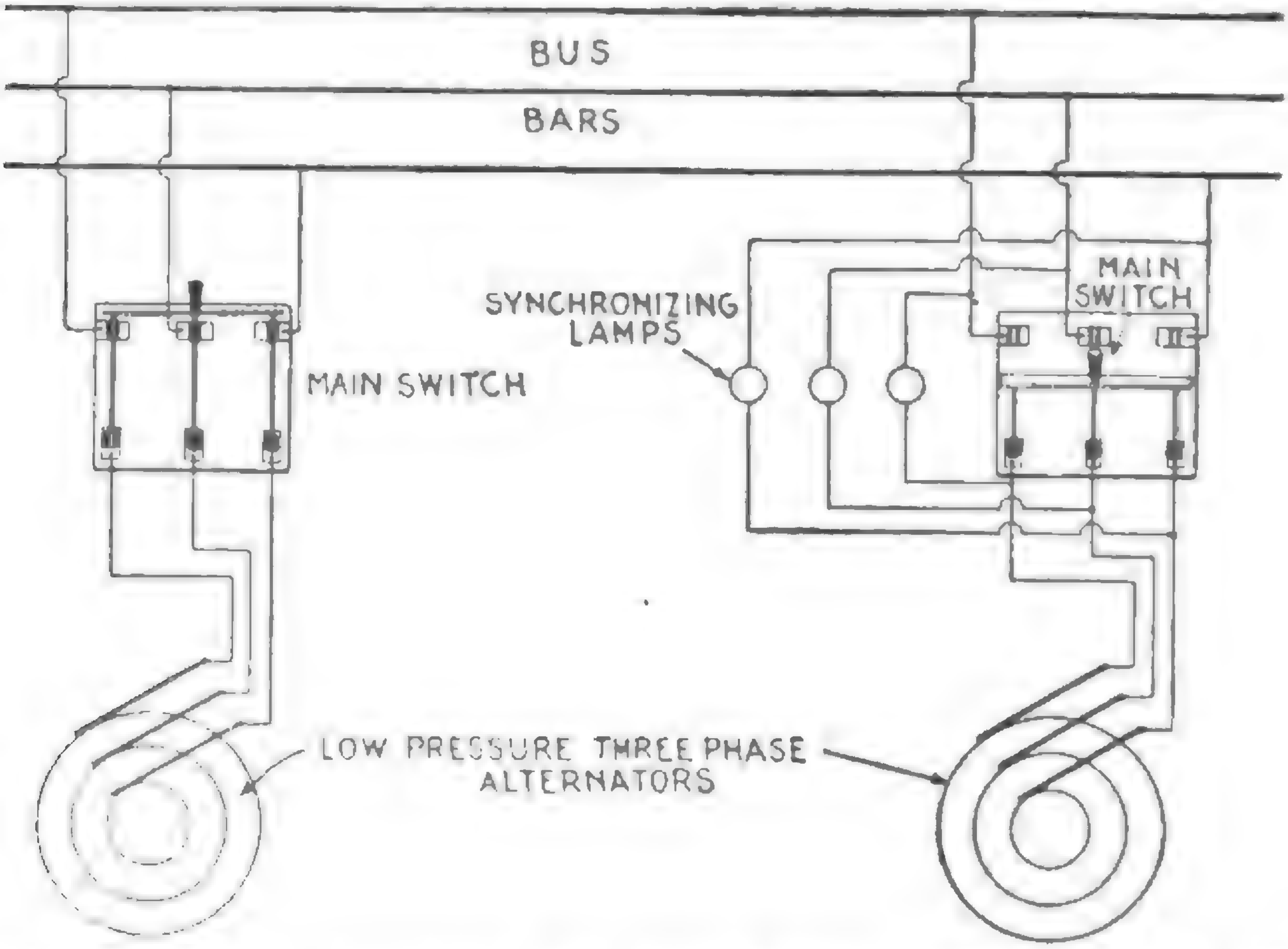

BUS
BARS
MAIN SWITCH
SYNCHRONIZING LAMPS
MAIN SWITCH
LOW PRESSURE THREE PHASE ALTERNATORS

FIG. 2,851.—Method of synchronizing three phase alternators with, three lamps, being an extension of the single phase method.

Ques. What is the disadvantage of the lamp method of synchronizing?

Ans. Lack of sensitiveness.

Ques. Which is the accepted lamp method, dark or brilliant?

Ans. In the United States it is usual to make the connections for a dark lamp at synchronism, while in England the opposite practice obtains.

With the dark lamp method, the breaking of a filament might cause the machines to be connected with a great phase difference, whereas, with the brilliant lamp it is difficult to determine the point of maximum brilliancy. This latter method, therefore may be called the safer.

Ques. What may be used in place of lamps for synchronizing?

Ans. Some form of synchroscopes, or synchronizers.

Ques. How does the Lincoln synchronizer work?

Ans. The construction is such that a hand moves around a dial so that the angle between the hand and the vertical is always the phase angle between the two sources of electric pressure to which the synchronizer is connected.

If the incoming alternator be running too slow, the hand deflects in one direction, if too fast, in the other direction. When the hand shows no deflection, that is, when it stands vertical, the machines are in phase. A complete revolution of the hand indicates a gain or loss of one cycle in the frequency of the incoming machine, as referred to the bus bars.

Cutting Out Alternator.—When it is desired to cut out of circuit an alternator running in parallel with others, the method of procedure is as follows:

1. Reduce driving power until the load has been transferred to the other alternators, adjusting field rheostat to obtain minimum current;
2. Open main switch;
3. Open field switch.

Ques. What precaution should be taken?

Ans. *Never* open field switch before main switch.

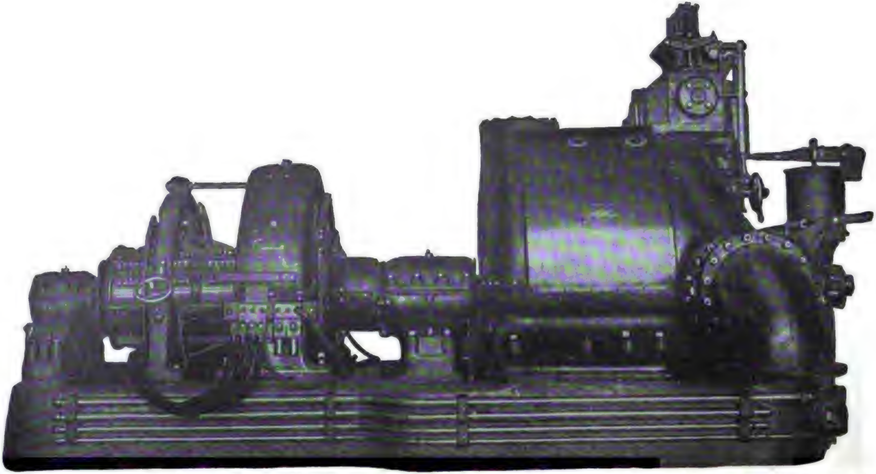


Fig. 2,852.—General Electric 500 kw., horizontal mixed pressure Curtis turbine connected to a 500 kw. dynamo. In a Curtis turbine it is not necessary to use the whole periphery of the first stage for low pressure steam nozzles. A section can be partitioned off and equipped with special expanding nozzles to receive steam at high pressure direct from the boilers. Such nozzles deliver their steam against the same wheel as do the low pressure nozzles, but occupy only a small portion of its periphery. The steam is expanded in these nozzles from high pressure all the way down to the normal pressure of the first stage, and in such expansion acquires a high velocity and consequently contains a great deal of energy—much more than does an equal quantity of low pressure steam. In consequence of this, high pressure steam is used with a far lower water rate than is obtained with low pressure steam, or with high pressure steam reduced to low pressure in a reducing valve. This construction is called "mixed pressure." Its function is the same as that of the reducing valve, that is, it makes up for a deficiency of low pressure steam by drawing direct on the boilers. With this construction, the full power of the turbine can be developed with: All low pressure steam, all high pressure steam, or, any necessary proportion of steam of each pressure. Furthermore, the transition from all low pressure to all high pressure, through all the conditions intermediate between these extremes, is provided for automatically by the turbine governor; a deficiency of low pressure steam causes the high pressure nozzles to open automatically.

Ques. What is the ordinary method of cutting out an alternator?

Ans. The main switch is usually opened without any preliminaries.

Ques. What is the objection to this procedure?

Ans. It suddenly throws all the load on the other alternators, and causes "hunting."

Ques. What forms of drive are especially desirable for running alternators in parallel, and why?

Ans. Water turbine or steam turbine because of the uniform torque, thus giving uniform motion of rotation.

With reciprocating engines, the crank effect is very variable during the revolution, resulting in pulsations driving the alternator too fast or too slow, and causing cross current between the alternators.

Ques. Is a sluggish, or a too sensitive governor preferable on an engine driving alternators in parallel?

Ans. A sluggish governor.

Alternators in Series.—Alternators are seldom if ever connected in series, for the reason that the synchronizing tendency peculiar to these machines causes them to oppose each other and fall out of phase when they are joined together in this way. If, however, they be directly connected to each other, or to an engine, so that they necessarily keep in phase at all times, and

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NOTE.—According to the practice of the General Electric Co., 2½ degrees of phase difference from a mean is the limit allowable in ordinary cases. It will, in certain cases, be possible to operate satisfactorily in parallel, or to run synchronous apparatus from machines whose angular variation exceeds this amount, and in other cases it will be easy and desirable to obtain a better speed control. The 2½ degree limit is intended to imply that the maximum departure from the mean position during any revolution shall not exceed 2½ ÷360 of an angle corresponding to two poles of a machine. The angle of circumference which corresponds to the 2½ degree of phase variation can be ascertained by dividing 2½ by ½ the number of pole; thus, in a 20 pole machine, the allowable angular variation from the mean would be 2½+10=¼ of one degree.

thus add their respective voltages instead of counteracting them, series operation is possible.

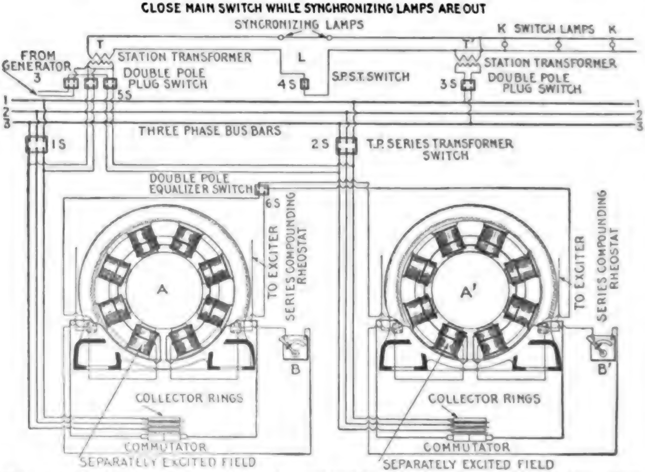

CLOSE MAIN SWITCH WHILE SYNCHRONIZING LAMPS ARE OUT
SYNCRONIZING LAMPS
K SWITCH LAMPS K
T
T'
FROM GENERATOR 3
STATION TRANSFORMER
DOUBLE POLE PLUG SWITCH
5S
L
4S
S.P.S.T. SWITCH
3S
STATION TRANSFORMER
DOUBLE POLE PLUG SWITCH
1
2
3
THREE PHASE BUS BARS
1S
2S
T.P. SERIES TRANSFORMER SWITCH
DOUBLE POLE EQUALIZER SWITCH
6S
TO EXCITER
SERIES COMPOUNDING RHEOSTAT
A
B
A'
B'
COLLECTOR RINGS
COMMUTATOR
SEPARATELY EXCITED FIELD

FIG. 2,853.—Diagram of connections for synchronizing two compound wound three phase alternators. A and A' are the armatures of the two machines, the fields of which are partly separately excited, the amount of excitation current being controlled by the series compounding rheostats B and B', which form a stationary shunt. It is assumed that the alternator A is connected to the bus bars 1, 2, and 3, by the switch 1S. If an increase make it necessary to introduce the alternator A', it is first run up to speed and excited to standard pressure by its exciter, and then the double plug switch 3S is closed, connecting the primary of the station transformer T and T' with the bus bars through the secondary coil, so that the synchronizing lamps light up when the secondary circuit is closed through the single pole switch 4S. The primary of the station transformer T is thus excited through the double pole switch 5S, connecting it with the outer terminals of the armature A'. The two alternators will now work in opposition to each other upon the synchronizing lamps, the transformer T being operated by the new alternator A' through the switch 2S, and the transformer T' being operated by the working alternator A, from the bus bars. If the new alternator be not in step with the working alternator, the synchronizing lamps will glow, growing brighter and dimmer alternately with greater or lesser rapidity. In this case, the armature speed of the new alternator must be controlled in such a manner that the brightening and dimming will occur more and more slowly, until the lamps cease to glow or remain extinguished for a decided interval of time. The extinction of the light is due to the disappearance of the secondary current, and indicates that the alternators are in step. The switch 2S should now be thrown, thus coupling the two machines electrically, and both of them will continue to operate in step. The double pole equalizer switch 6S should now be closed, connecting the two field windings in parallel and equalizing the compounding, so that any variations of load will affect the two alternators equally. After the alternators have been connected in parallel, the switches 4S and 5S, may be opened leaving the switch 3S closed, to operate the switchboard lamps K, K, as pilot lights from the bus bars.

Transformers.—These, as a whole, are simple in construction, high in efficiency, and comparatively inexpensive. Their principles of operation are also readily understood.

The efficiency of a transformer, that is, the ratio between full load primary and full load secondary is greatest when the load on it is such that the sum of the constant losses equals the sum of the variable losses.

In general, transformers designed for high frequencies and large capacities are more efficient than those designed for low frequencies and small capacities. As a whole, however, a transformer leaves but little to be desired as regards efficiency, a modern 60 cycle transformer of 50 kilowatts capacity or more possesses an efficiency of approximately 98 per cent. at full load and an efficiency of about 97 per cent. at half load.

Ques. How should a transformer be selected, with respect to efficiency?

Ans. One should be chosen, whose parts are so proportioned that the point of maximum efficiency occurs at that load which the transformer usually carries in service.

In many alternating current installations, comparatively light loads are carried the greater part of the time, the rated full load or an overload being occurrences of short durations. For such purposes special attention should be given to the designing or selecting of transformers having low core losses rather than low resistance losses, because the latter are then of relatively small importance.

Ques. What kind of efficiency is the station manager interested in?

Ans. The "all day efficiency."

This expression, as commonly met with in practice, denotes *the percentage that the amount of energy actually used by the consumer is of the total energy supplied to his transformer during 24 hours.* The formula for calculating the all day efficiency of a transformer is based upon the supposition that the amount of energy used by the consumer d

24 hours is equivalent to full load on his transformer during five hours and is as follows:

$$E = \frac{5w}{24c + 5r + 5w}$$

where

E = the all day efficiency of the transformer,
w = the full load in watts on the primary,
c = the core loss in watts,
r = the resistance loss in watts.

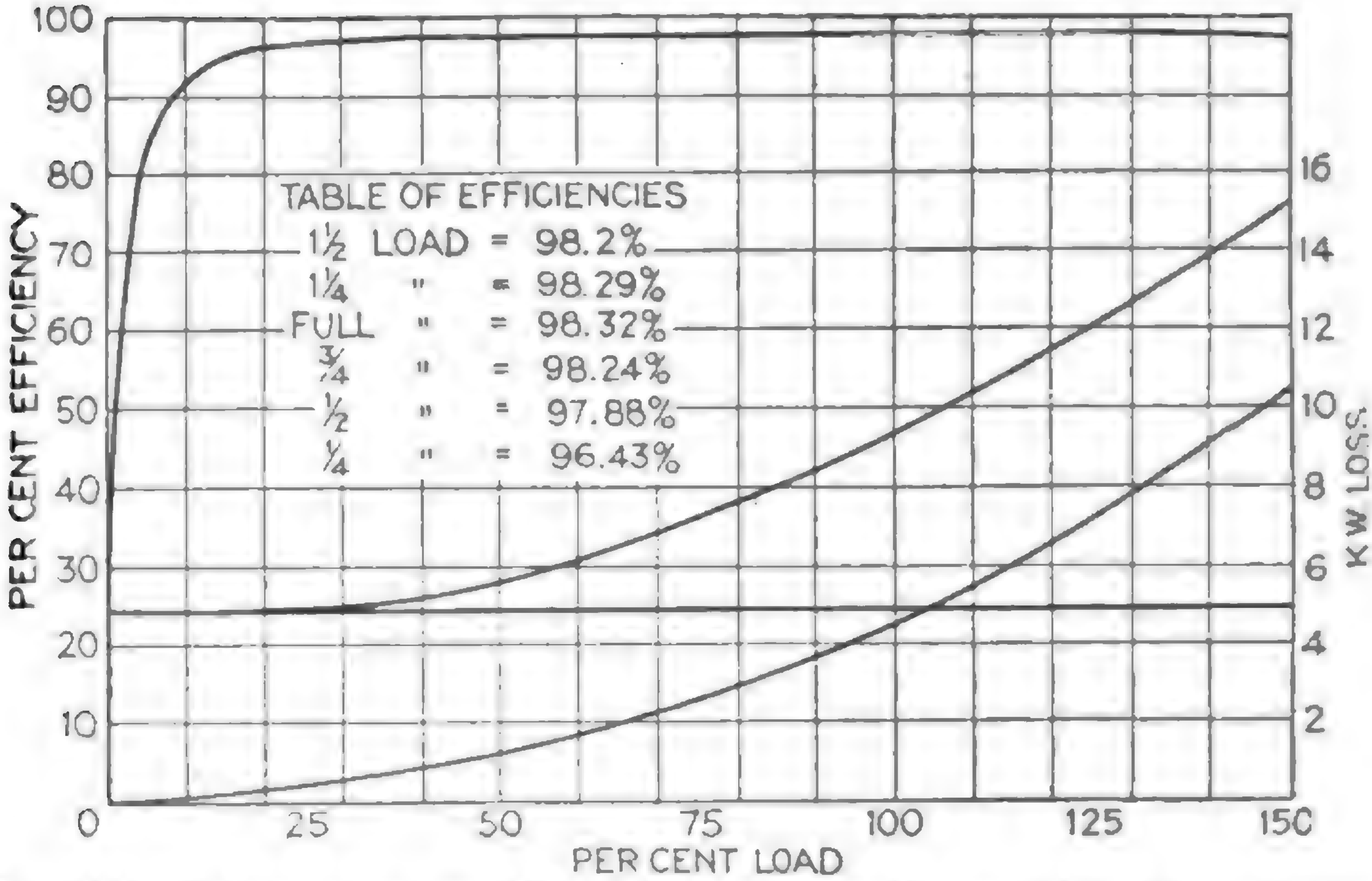


FIG. 2,854.—Performance curves of Westinghouse air blast 550 kw, 10,500 volt transformer. 3,000 alternations.

Ques. What are the usual all day efficiencies?

Ans. The average is about 85 per cent. for those of 1 kilowatt capacity, 92 per cent. for those of 5 kilowatts capacity, 94 per cent. for those of 10 kilowatts capacity, and about 94.5 per cent. for those of 15 kilowatts capacity.

Ques. What becomes of the energy lost by a transformer?

Ans. It reappears as heat in the windings and core.

This heat not only increases the resistances of the windings and core, producing thereby a further increase of their respective losses, but in addition causes in time a peculiar effect on the iron core which is intensified by the reversals of magnetism constantly going on within it.

After about two years' service, the iron apparently becomes fatigued or tired, and this phenomenon is called aging of the iron. Since the life of the transformer depends to a great extent upon this factor, the conditions responsible for its existence should as far as possible be removed. Means must therefore be provided in the construction to radiate the heat as quickly as it is generated.

Ques. What kind of oil is used in oil cooled transformers?

Ans. Mineral oil.

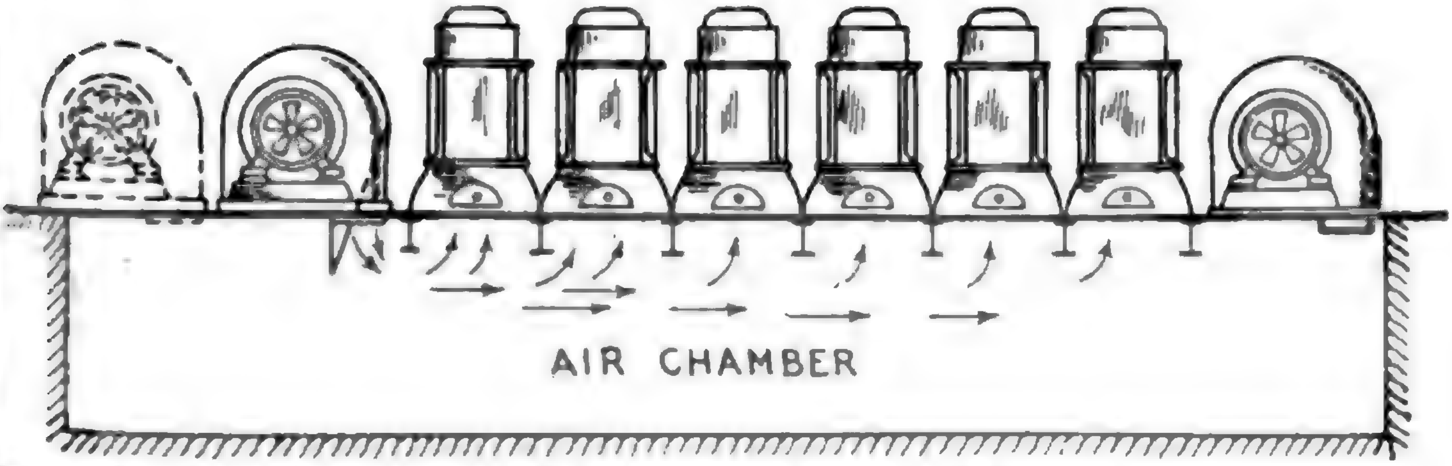


FIG. 2,855.—General arrangement of air blast transformers and blowers.

Ques. How is it obtained?

Ans. By fractional distillations of petroleum unmixed with any other substances and without subsequent chemical treatment.

Ques. What is the important requirement for transformer oil?

Ans. It should be free from moisture, acid, alkali or sulphur compounds.

Ques. How may the presence of moisture be determined?

Ans. By thrusting a red hot iron rod in the oil; if it "crackle," moisture is present.

Ques. Describe the Westinghouse method of drying oil.

Ans. It is circulated through a tank containing lime, and afterwards, through a dry sand filter.

Ques. What is the objection to heating the oil (raising its temperature slightly above boiling point of water) to remove the moisture?

Ans. The time consumed (several days) is excessive.

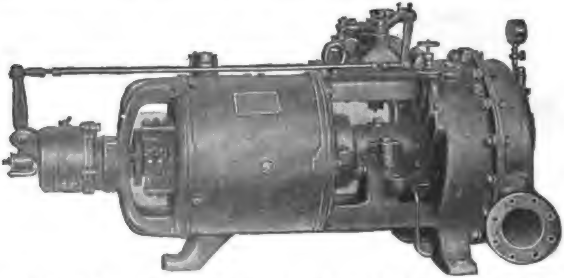


FIG. 2,856.—Small Curtis turbine generator set as made by the General Electric Co., in sizes from 5 kw., to 300 kw. It can be arranged to operate either condensing or non-condensing, and at any steam pressure above 80 lbs. for the smaller sizes and 100 lbs. for the larger. There are only two main bearings. A thrust bearing, consisting of roller bearings and running between hardened steel face washers located at either end of the main bearings is provided solely for centering the rotor so as to equalize the clearance. A centrifugal governor is provided (in the smaller sizes) completely housed, and mounted directly on the main shaft end. It controls a balanced poppet valve through a bell crank. In the larger sizes (75 kw. and above) the governor is mounted on a vertical secondary shaft geared to the main shaft and controls a cam shaft which opens or closes a series of valves in rotation, admitting the steam to different sections of the first stage nozzles. In this way throttling of the steam is avoided. There is also an emergency governor which closes the throttle valve in the event of the speed reaching a predetermined limit. The speeds of operation range from 5,000 R.P.M. for the smallest size to 1,500 R.P.M. for the largest. The lubrication system is enclosed and is automatic. Air leakage where the shaft passes through the wheel casing is prevented by steam seal.

Ques. What effect has moisture?

Ans. It reduces the insulation value of the oil. .06 per cent. of moisture has been found to reduce the dielectric strength of oil about 50 per cent. "dry" oil will withstand a pressure of 25,000 volts between two 9½ inch knobs separated .15 inch.

Ques. What is understood by transformer regulation?

Ans. It is the difference between the secondary voltage at no load and at full load, and is generally expressed as a percentage of the secondary voltage at no load.

Ques. What governs its value?

Ans. The resistance and reactance of the windings.

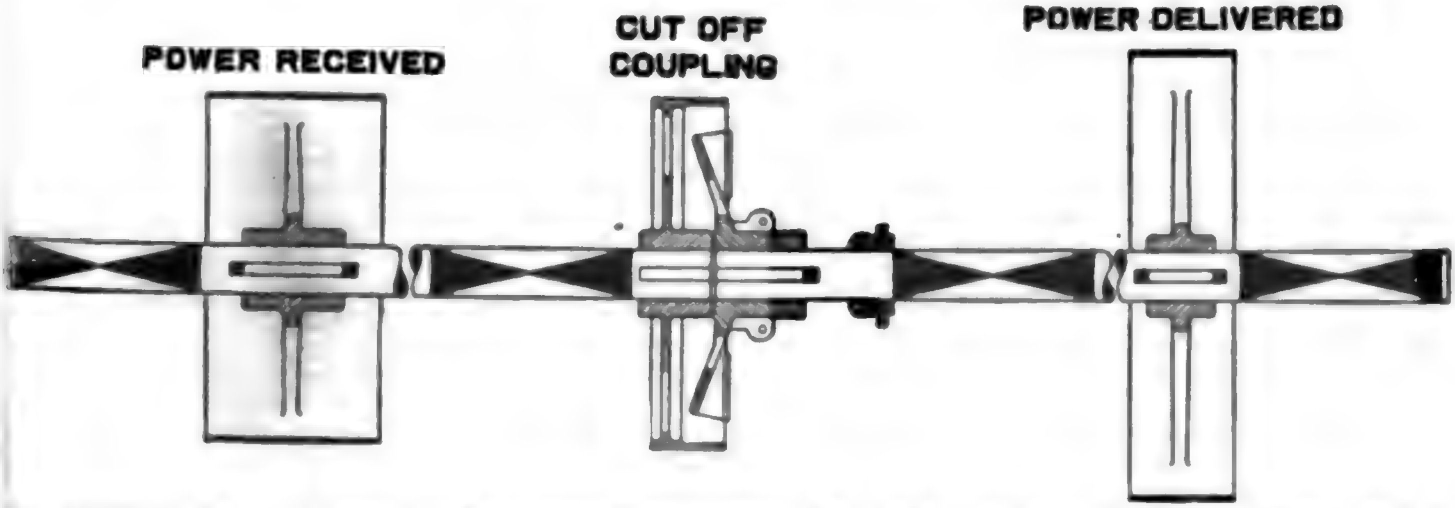


FIG. 2,857.—Cut off coupling for power transmission by line shafting. It is used to cut off a driving shaft from a driven shaft. Its use obviates the use of a *quill*, such as is shown in fig. 2,858.

Ques. How may the regulation be improved?

Ans. By decreasing the resistances of the windings by employing conductors of greater cross section, or decreasing their reactance by dividing the coils into sections and closely interspersing those of the primary between those of the secondary.

NOTE.—*The term "regulation"* as here used is synonymous with "drop." The *voltage drop* in a transformer denotes the drop of voltage occurring across the secondary terminals of a transformer with load. This drop is due to two causes: 1, the resistance of the windings; and 2, the reactance or magnetic leakage of the windings. On non-inductive load, the reactive drop, being in quadrature, produces but a slight effect, but on inductive loads it causes the voltage to drop, and on *leading current loads* it causes the voltage to rise. As the voltage drop of a good transformer is very small even on inductive load, direct accurate measurement is difficult. It is best to measure the copper loss with short circuited secondary by means of a wattmeter, and at the same time the voltage required to drive full load current through. From the watts, the resistance drop can be found, and from this and the impedence voltage, the reactive drop may be calculated. From these data a simple vector diagram will give, near enough for all practical purposes, the drop for any power factor, or the following formula may be used which has been deduced from the vector diagram. $D = \sqrt{(W+X)^2 + (R+P)^2} - 100$ where R = % resistance drop; X = % reactive drop; P = % power factor of load; W = % wattless factor of load ($\sqrt{1-P^2}$); D = % resultant secondary drop. For non-inductive loads where P = 100 and W = 0, $D = \sqrt{X^2 + (100+R)^2} - 100$. In the case of leading currents it should be consi negative.

In transformers where there is a great difference in voltage between the primary and secondary windings, however, this remedy has its limitations on account of the great amount of insulation which must necessarily be used between the windings, and which therefore causes the distances between them to become such as to cause considerable leakage of the lines of force.

Ques. How does the regulation vary for different transformers, and what should be the limit?

Ans. Those of large capacity usually have a better regulation than those of small capacity, but in no case should its value exceed 2 per cent.

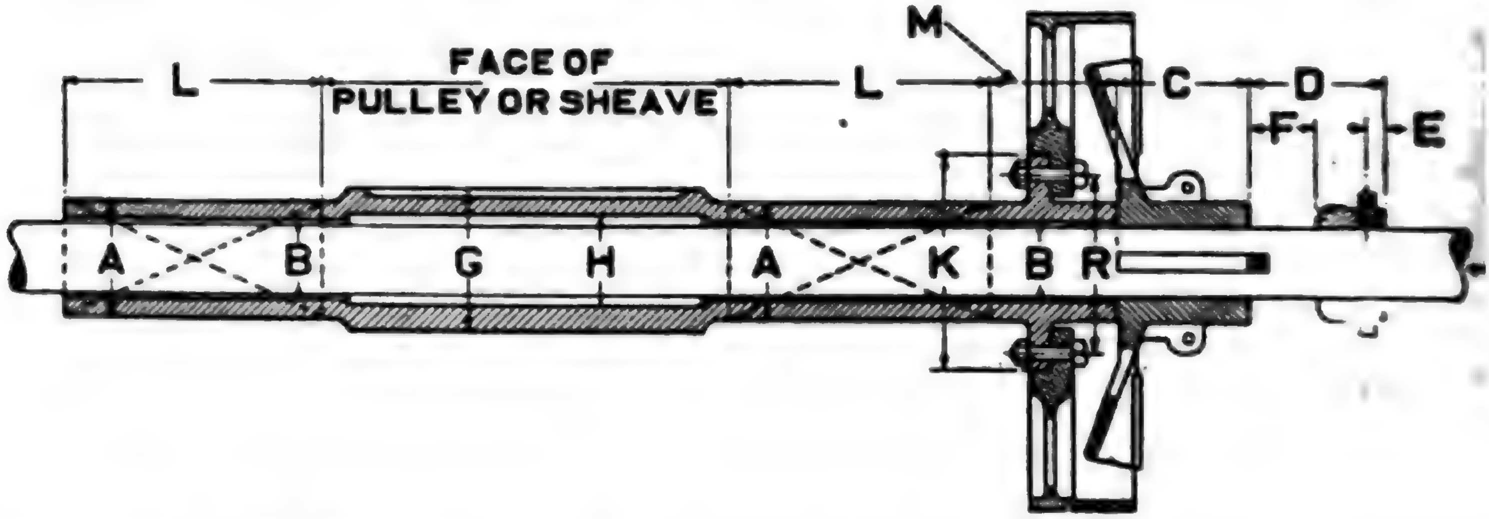


FIG. 2,858.—Quill drive. This is the proper transmission arrangement substitute for heavy service, requiring large pulleys, sheaves, gears, rotors, etc. It is a hollow shaft supported by independent bearings. The main driving shaft running through the quill is thus relieved of all transverse stresses. The power is transmitted to the quill by means of a friction or jaw clutch. When the clutch is thrown out the pulley or sheave stands idle and the driving shaft revolves freely within the quill. As there is no contact between moving parts there is no wear. Jaw clutches should be used for drives demanding positive angular displacement. They can only be thrown in and out of engagement when at rest. All very large clutch pulleys, sheaves, or gears designed to run loose on the line shaft are preferably mounted on quills. The letters A, B, C, etc., indicate the dimensions to be specified in ordering a quill.

Ques. What advantages have shell type transformers over those of the core type?

Ans. They have a larger proportion of core surface exposed for radiation of heat, and a shorter magnetic circuit which reduces the tendency for a leakage of the lines of force into the air.

Both types have advantages and disadvantages as compared with the other. In the shell type, there is less magnetic leakage, but also less surface exposed for radiation, and greater difficulty in providing efficient insulation between the two circuits; in the core type there is more surface exposed for radiation and less difficulty in insulating the windings, but there is also a great leakage of the lines of magnetic force into the outer air.

Ques. How are the windings usually arranged?

Ans. As a rule, there is only one primary winding but the secondary winding is generally divided into two equal sections, the four terminals of which are permanently wired to four connection blocks which may be connected so as to throw the secondary sections either in parallel or in series with each other at will.

Ques. What is necessary for satisfactory operation of transformers in parallel?

Ans. They must be designed for the same pressures and capacities, their percentages of regulation should be the same and they must have the same polarity at a given instant.

One may satisfy himself as to the first of these conditions by examining the name plates fastened to the transformers, whereon are stamped the values of the respective pressures and capacities of each.

Although equal values of regulation is given as one of the conditions to be satisfied, transformers may be operated in parallel when their percentages of regulation are not the same. Ideal operation, however, can be attained only under the former state of affairs. Suppose, for instance, a transformer having a regulation of two per cent. be operated in parallel with another of similar size and design but having a regulation of one per cent. The secondary pressures of these transformers at no load will of course be the same, but at full load if the secondary pressure of the one be 98 volts, that of the other will be 99 volts. There will, therefore, be a difference of pressure of one volt between them which will tend to force a current backward through the secondary winding of the transformer delivering 98 volts. This reversed current, although comparatively small in value, lowers the efficiency of the installation by causing a displacement of phase and a decrease in the combined power factor of the transformers.

Ques. Describe the polarity test.

Ans. The test for polarity consists in joining together by means of a fuse wire, a terminal of the secondary winding of each transformer, and then with the primary windings supplied with normal voltage, connecting temporarily the remaining terminals of the secondary windings. The melting of the fuse wire thus connected indicates that the secondary terminals joined together are of opposite polarities, and that the connections must therefore be reversed, whereas if the fuse wire do not melt, it shows that the proper terminals have been joined and that the connections may be made permanent.

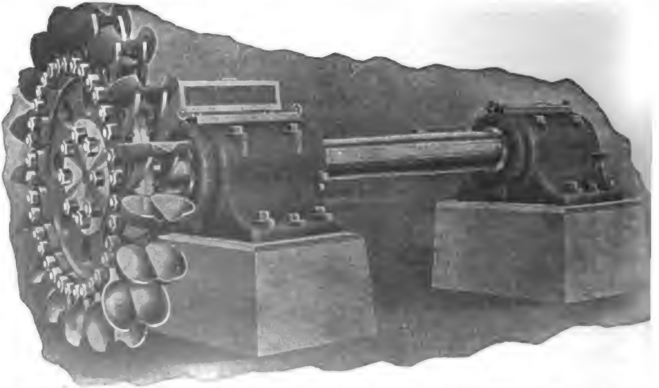


FIG. 2,859.—Single overhung tangential water wheel equipped with Doble ellipsoidal buckets. The central position of the front entering wedge or lip of the bucket is cut away in the form of a semi-circular notch, which allows a solid circular water jet to discharge upon the central dividing wedge of the bucket without being split in a horizontal plane.

The object of this test is, obviously, not to determine the exact polarity of each secondary terminal, but merely to indicate which of them are of the same polarity.

Motor Generators.—In motor generator sets, either the shunt or series wound type of motor may be employed at the power producing end of the set, but the field of the generator is either shunt or compound wound, depending upon whether or not it is desired to maintain or to raise the secondary voltage near full load. In either case a rheostat introduced in the shunt

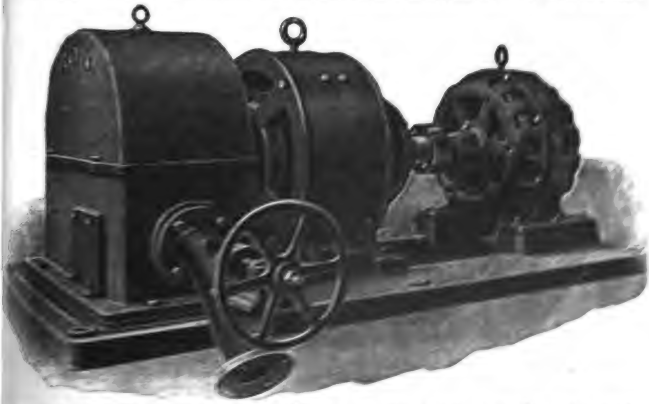


Fig. [illegible].—Motor generator [illegible] set [illegible] The [illegible] wheel [illegible] [illegible]

field winding of the generator will [illegible] Both generator and motor [illegible] respective commutators [illegible] this means ample space surrounds all of the working parts, and repairs can readily be made.

Motor generators are frequently used as boosters to raise or boost the voltage near the extremities of long distance, direct current transmission lines. Of these, electric railway systems in which it is desired to extend certain of the longer lines, form a typical example.

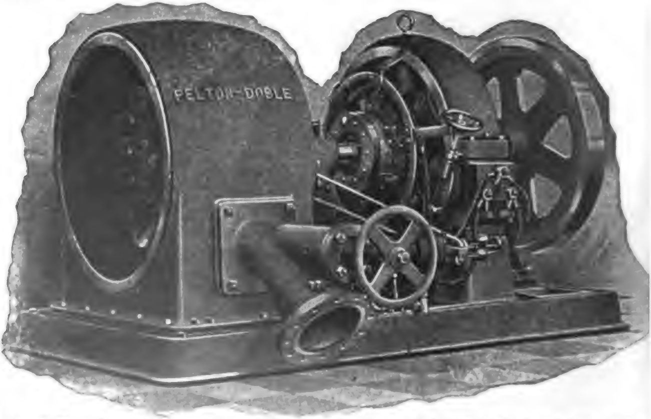


FIG. 2,861.—Automatically governed Pelton-Doble tangential water wheel driving exciter dynamo. The water wheel is mounted on one end of the shaft, while the opposite end is extended to carry a fly wheel of suitable design to compensate for the low fly wheel effect of the direct current armature. Two bearings support the shaft which carries the rotating elements of the unit. A needle nozzle actuated by a direct motion Pelton-Doble governor (designed for operation by either oil or water pressure) maintains constant speed.

Owing to the great cost of changing such a system over to one employing alternating current, or storage batteries, or of constructing an additional power station, these solutions of the problem are usually at variance with good judgment and the amount of money at hand. The choice then remains between the purchase of additional wire for feeders, the connection of a booster in the old feeders, or the installation of both larger feeders and a booster. Of these, it is generally found that either the second or the third mentioned alternative meets the conditions most satisfactorily.

A booster installed in a railway system for the purpose just mentioned, would have a series wound motor, and the conditions to which it must conform would be as follows: The motor having a series winding must provide for the full feeder current passing through both armature and field windings.

Owing to the varying loads on a railway system, due to the frequent starting and stopping of cars, the feeder current varies between zero and some such value as 150 amperes. This fluctuation of current through the field winding will, in ordinary cases, vary the magnetization of the pole pieces from zero almost to the point of saturation; that is, the maximum feeder current will so nearly fill the magnet cores with lines of force that it would be quite difficult to cause more lines of magnetic force to pass through them.

So long as the point of saturation is not reached, however, the proportion of current to field strength remains constant, and therefore the ratio of amperes to volts will not vary.

The severe fluctuations of the feeder current would, if the motor were shunt or compound wound, cause most serious sparking and various other troubles, but in a series motor where the back ampere turns on the armature that react on the field vary in precisely the same proportion as the ampere turns in the field, there exists at all times a tendency to balance the active forces and produce satisfactory operation. If, however, the field magnet cores be very large, they cannot so quickly respond, magnetically, to changes in the strength of the current, and there is then greater liability of the armature reaction momentarily weakening the field and thereby producing temporary sparking.

Ques. Are motor generators always composed of direct current sets?

Ans. No.

Ques. Describe conditions requiring a different combination.

Ans. For purposes where for instance direct currents of widely different voltages are to be obtained from an alternating current circuit, and it is desired to install but one set, a motor generator consisting of an alternating current motor such as an induction motor, and a dynamo must necessarily be employed.

In such sets, it is common to find both motor and dynamo armatures mounted on a common shaft, and the respective field frames resting on a single base, although for connection on a very high pressure alternating current circuit, separate armature shafts insulated from each other but directly connected together, and separate bases resting on a single foundation, are usually employed to afford the highest degree of insulation between the respective circuits of the two machines.

Ques. What is the objection to a set composed of alternating current motor and alternator?

Ans. The commercial field that would be naturally covered by such a set is better supplied by a transformer.

Ques. Why?

Ans. Because a transformer contains no moving parts, and is therefore simpler in construction, cheaper in price, and less liable to get out of order.

Dynamotors.—A dynamotor differs from a motor generator in that the motor armature and the generator armature are combined into one, thereby requiring but one field frame. Since the motor and generator armature windings are mounted on a single core, the armature reaction due to the one winding is neutralized by the reaction caused by the other winding. There is, consequently, little or no tendency for sparking to occur at the brushes, and they therefore need not be shifted on this account for different loads.

Ques. How is a dynamotor usually constructed?

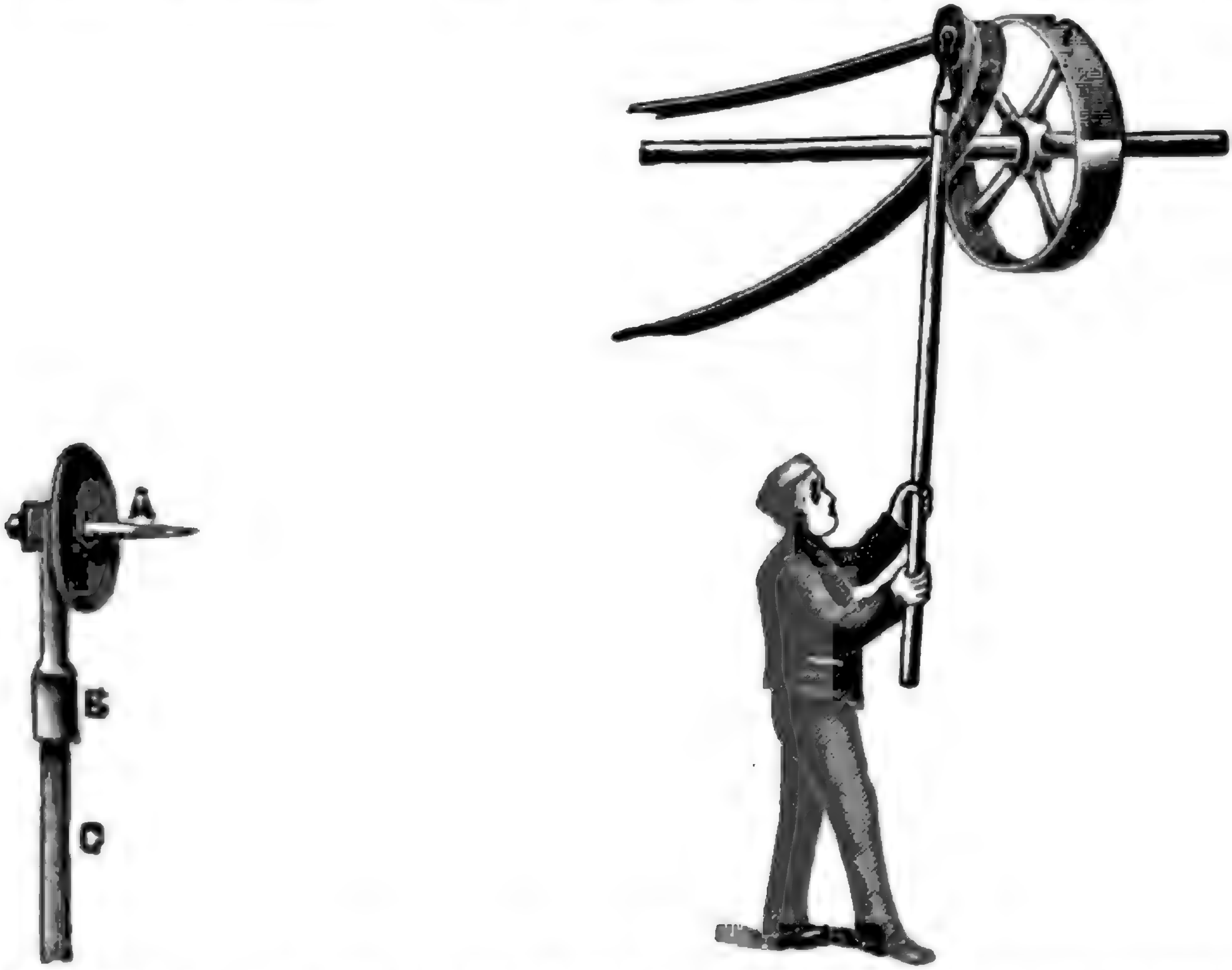
Ans. It is usually built with two pole pieces which are shunt wound.

Ques. Why does the voltage developed fall off slightly under an increase of load?

Ans. Because a compound winding cannot be provided.

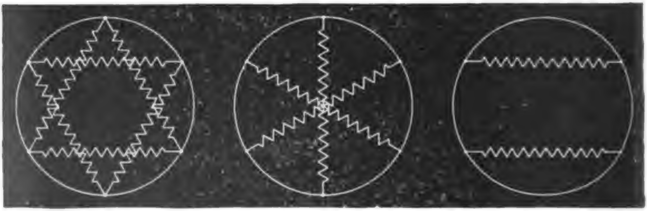
Ques. Describe the armature construction and operation.

Ans. It consists of two separate windings; one of which is joined to a commutator mounted on one side of the armature for motor purposes, and the other to the commutator on the other side of the armature for generator purposes.



Figs. 2,862 and 2,863.—Method of putting on belts when the driver is in motion, and device used. The latter is called a *belt slipper*, and consists, as shown in fig. 2,862, of a cone and shield, which revolve upon the stem, B, thus yielding easily to the pull of the belt. A staff or handle C of any convenient length can be fastened to the socket. The mode of operation is illustrated in fig. 2,863, which is self explanatory.

By means of two studs of brushes pressing on the motor commutator, current from the service wires is fed into the winding connected to this commutator, and since the shunt field winding is also excited by the current from the service wires, there is developed in the generator winding on the rotating armature a direct voltage which is proportional to the speed of rotation of the armature in revolutions per



FIGS. 2,864 to 2,866.—Converter connections; fig. 2,864 double delta connection; fig. 2,865 diametrical connection; fig. 2,866 two circuit single phase connection. For six phase synchronous converter, two different arrangements of the connections are generally used. One is called the *double delta*, and the other the *diametrical* connection. Let the armature winding of the converter be represented by a circle as in figs. 2,864 and 2,865, and let the six equidistant points on the circumference represent collector rings, then the secondary of the supply transformers can be connected to the collector rings in a *double delta* as in fig. 2,864, or across diametrical pairs of pointer as in fig. 2,865. In the first instance, the voltage ratio is the same as for the three phase synchronous converter and simply consists of two delta systems. The transformers can also be connected in double star, and in such a case the ratio between the three phase voltage between the terminals of each star, and the direct voltage will be the same as for double delta, while the voltage of each transformer coil, or voltage to neutral, is $1 \div \sqrt{3}$ times as much. With the diametrical connection, the ratio is the same as for the two ring single phase converter, it being analogous to three such systems. Hence six phase double delta $E_1 = \sqrt{3}E \div 2\sqrt{2} = .612E$. Six phase diametrical, $E_1 = E \div \sqrt{2} = .707E$. The ratio of the virtual voltage E_0 between any collector ring and the neutral point is always $E_0 = E \div 2\sqrt{2} = .354E$. For single phase synchronous converters, consisting of a closed circuit armature winding tapped at two equidistant points to the two collector rings the virtual voltage is $1 \div \sqrt{2} \times$the direct current voltage. While such an arrangement of the single phase converter is the simplest, requiring only two collector rings, it is undesirable, especially for larger machines, on account of excessive heating of the armature conductors. In fig. 2,866, which represents the armature winding of a single phase converter, the supply circuits from two secondaries of the step down transformers are connected to four collector rings, so that the two circuits are in phase with each other, but each spreads over an arc of 120 electrical degrees instead of over 180 degrees as in the single phase circuit converter. To distinguish the two types, it is generally called a two circuit single phase synchronous converter. The virtual voltage E_2 bears to the direct voltage the same relation as in the three phase converter, that is single phase two circuit, $E_1 = \sqrt{3} \div 2\sqrt{2} = .612E$.

second, the number of conductors in series which constitute the generator winding, and the total strength of the field in which the armature revolves. This pressure causes current to pass through the generator winding and the distributing circuit when the distributing circuit to which this winding is connected by means of its respective commutator, brushes, etc., is closed.

Ques. How is a dynamotor started?

Ans. It is connected at its motor end and started in the same manner as any shunt wound motor on a constant pressure circuit.

Ques. What precautions should be taken in starting a dynamotor?

Ans. The necessary precautions are, to have the poles strongly magnetized before passing current through the motor winding on the armature; to increase gradually the current through this winding, and not to close the generating circuit until normal conditions regarding speed, etc., are established in the motor circuit.

Ques. How is the current developed in the machine regulated?

Ans. It can be regulated by the introduction of resistance in one or the other of the armature circuits, or by a shifting of the brushes around the commutator.

Ques. Are dynamotors less efficient than motor generators of a similar type?

Ans. No, they are more efficient.

Ques. Why?

Ans. Because they have only one field circuit and at least one bearing less than a motor generator.

A motor generator has at least three bearings, and occasionally, four, where the set consists of two independent machines directly connected together.

Rotary Converters.—An important modification of the dynamotor is the rotary converter. This machine forms, as it were, a link between alternating and direct current systems,

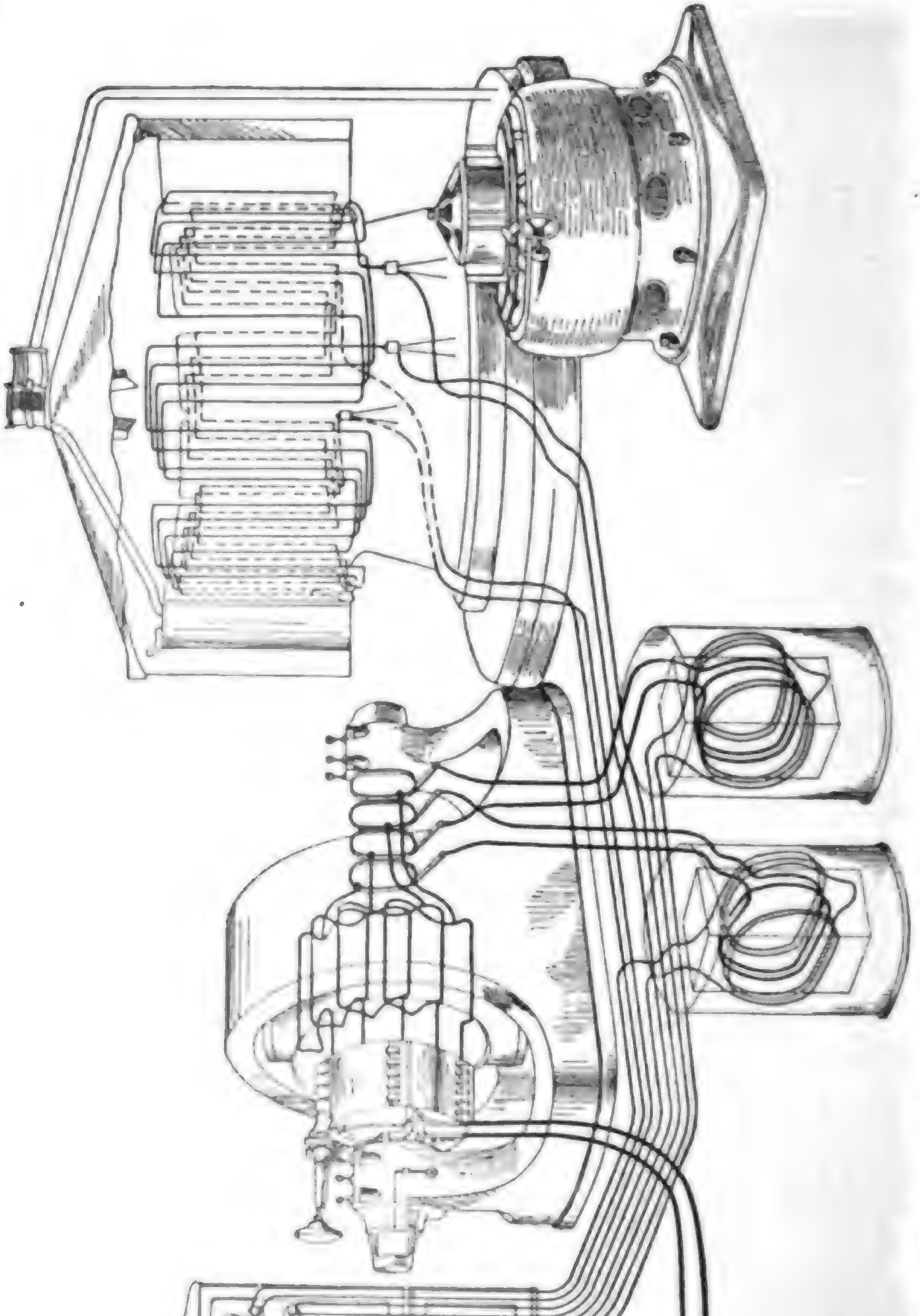


FIG. 2,867.—Skeleton diagram showing wiring of alternator, exciter, transformer and converter. The cut also shows switchboard and connections.

being in general a combination of an alternating current motor and a dynamo.

It has practically become a fixture in all large electric railway systems and in other installations where heavy direct currents of constant pressure are required at a considerable distance from the generating plant. In such cases a rotary converter is installed in the sub-station, and being simpler in construction, higher in efficiency, more economical of floor space, and lower in price than a motor generator set consisting of an alternating current motor and a dynamo which might be used in its place, it has almost entirely superseded the latter machine for the class of work mentioned.

Ques. What is the objection to the single phase rotary converter?

Ans. It is not self-starting.

Ques. What feature of operation is inherent in a rotary converter?

Ans. A rotary converter is a "reversible machine."

That is to say, if it be supplied with direct current of the proper voltage at its commutator end, it will run as a direct current motor and deliver alternating current to the collector rings. While this feature is sometimes taken advantage of in starting the converter from rest, the machine is not often used permanently in this way, its commercial application being usually the conversion of alternating currents into direct currents.

Ques. How does a rotary converter operate when driven by direct current?

Ans. The same as a direct current motor, its speed of rotation depending upon the relation existing between the strength of the field and the direct current voltage applied.

If the field be weak with respect to the armature magnetism resulting from the applied voltage, the armature will rotate at a high speed, increasing until the conductors on the armature cut the lines of force in the field so as to develop a voltage which will be equal to that applied.

Again, if the field be strong with respect to the armature magnetism, resulting from the applied voltage, the armature will rotate at a low speed. If, therefore, it be desired to operate the converter in this manner and maintain an alternating current of constant frequency, the speed of rotation must be kept constant by supplying a constant voltage not only to the brushes pressing on the commutator, but also to the terminals of the field winding.

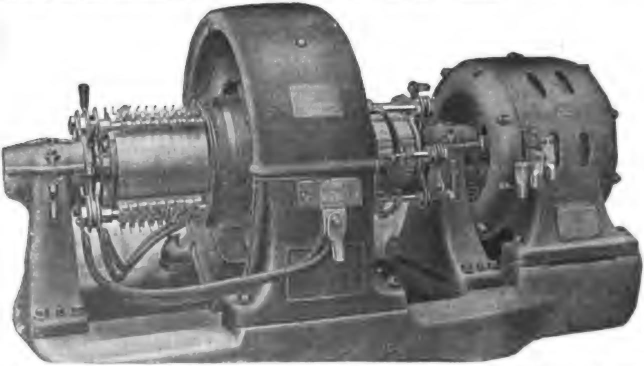


FIG. 2,868.—General Electric synchronous converter with series booster. This type of converter generally consists of an alternator with revolvong field mounted on the same shaft as the converter armature. The armature of the alternator, or booster, as it is usually called, is stationary and connected electrically in series between the supply circuit and the collector rings of the synchronous converter. The booster field has the same number of pole as the converter and is generally shunt wound. A change in the booster voltage will correspondingly change the alternating voltage impressed on the converter and this regulation can, of course, be made so as to either increase or decrease the impressed voltage by means of strengthening or weakening the booster field. The voltage variation can be made either non-automatic or automatic, and in the latter case, it becomes necessary to provide a motor operated rheostat controlled by suitable relays, or the booster can be provided with a series field. By means of a booster, it is possible to vary the direct voltage of the converter with a constant alternating supply voltage, and this voltage regulation is obtained without disturbance of the power factor or wave shape of the system. Synchronous converters are frequently installed in connection with Edison systems, where three wire direct current is required. The three wire feature is obtained either by providing extra collector rings and compensator, as with ordinary direct current generators, or also by connecting the neutral wire directly to the neutral point of the secondary winding of step down transformers, if such be furnished.

Ques. How does it operate with alternating current drive?

Ans. The same as a synchronous motor.

Ques. What is the most troublesome part and why?

Ans. The commutator, because of the many pieces of which it is composed and the necessary lines along which it is constructed, its peripheral speed must be kept within reasonable limits.

Ques. What should be the limit of the commutator speed?

Ans. The commutator speed, or tangential speed at the brushes should not exceed 3,000 feet per minute.

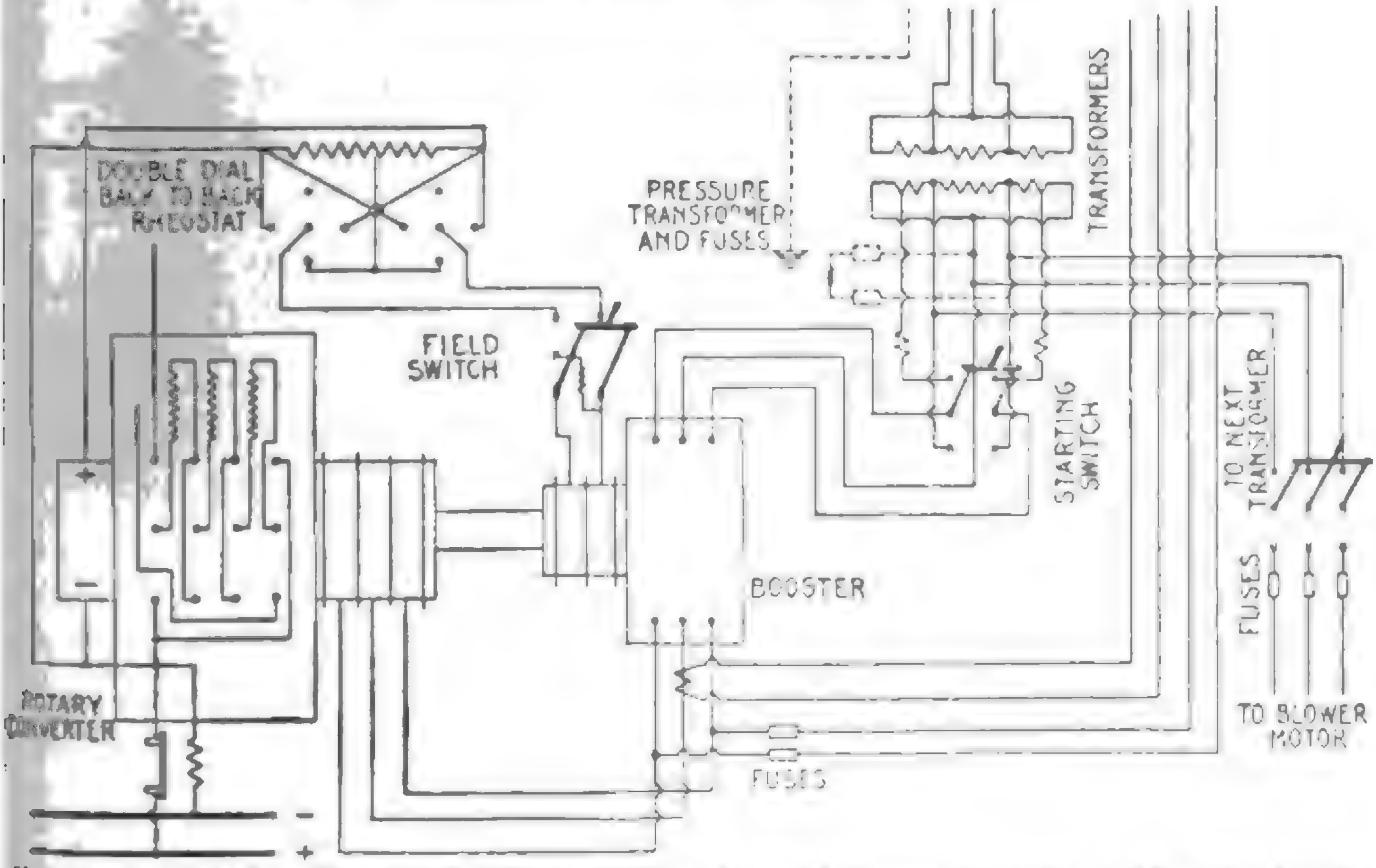

DOUBLE DIAL BACK TO BACK RHEOSTAT
PRESSURE TRANSFORMER AND FUSES
TRANSFORMERS
FIELD SWITCH
STARTING SWITCH
TO NEXT TRANSFORMER
FUSES
BOOSTER
TO BLOWER MOTOR
ROTARY CONVERTER
FUSES
-
+

FIG. 2,869.—Wiring diagram for General Electric synchronous converter with series booster as illustrated in fig. 2,868.

Ques. Name another limitation necessary for satisfactory operation.

Ans. The pressure between adjacent commutator bars should not exceed eight or ten volts.

If the commutator bars be made narrow in order to obtain the necessary number for the desired voltage with the minimum circumference and therefore low commutator speed, the brushes employed to collect the current are liable to require excessive width in order to provide the proper cross section and yet not cover more than two bars at once.

Ques. How can the commutator speed be kept within reasonable limits, other than by reducing the width of the commutator bars?

Ans. By using alternating current of comparatively low frequency.

For a rotary converter delivering 500 volt direct current, the proper frequency for the alternating current circuit has been found to be 25 cycles per second.

Ques. When a rotary converter is operated in the usual manner on an alternating current circuit, how can the direct current be varied?

Ans. It may be varied (from zero to a maximum) by changing the value of the alternating pressure supplied to the machine, or it may be altered within a limited range by moving the brushes around the commutator, or in a compound wound converter by changing the amount of compounding.

Under ordinary conditions, varying the voltage developed by changing the voltage at the motor end is not practical, hence the voltage developed can be varied only over a limited range. In addition to this, the voltage developed at the direct current end bears always a certain constant proportion to the alternating current voltage applied at the motor end; this is due to the same winding being used both for motor and generator purposes. In all cases the proportion is such that the alternating current voltage is the lower, being in the single phase and in the two phase converters about .707 of the direct current voltage, and in the three phase converter about .612 of the direct current voltage. It is thus seen that whatever value of direct current voltage be desired, the value of the applied alternating current voltage must be lower, requiring in consequence the installation of step down transformers at the sub-station for reducing the line wire voltage to conform to the direct current pressure required.

Ques. What is the efficiency of a rotary converter?

Ans. It may be said to have approximately the same efficiency as that in the average of the same output, although in reality the converter is a trifle more efficient on account of affording a somewhat shorter average path for the current in the armature, reducing in consequence the resistance loss and the armature reaction.

Ques. May a converter be overloaded more than a dynamo of the same output, and why?

Ans. Yes, because there is usually less resistance loss in the armature of the converter than in the armature of the dynamo.

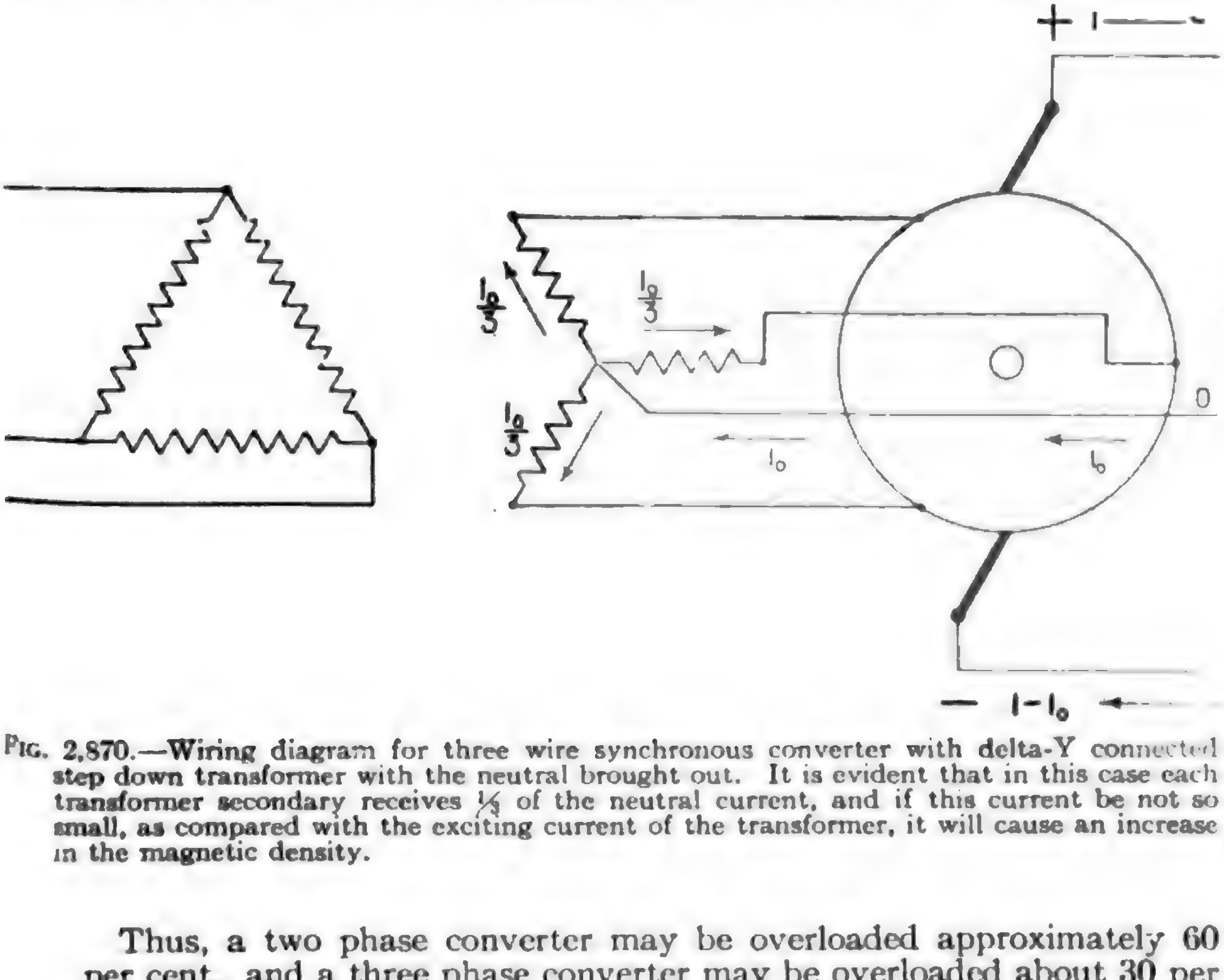


FIG. 2,870.—Wiring diagram for three wire synchronous converter with delta-Y connected step down transformer with the neutral brought out. It is evident that in this case each transformer secondary receives ⅓ of the neutral current, and if this current be not so small, as compared with the exciting current of the transformer, it will cause an increase in the magnetic density.

Thus, a two phase converter may be overloaded approximately 60 per cent., and a three phase converter may be overloaded about 30 per cent. above their respective outputs if operated as dynamos.

Ques. Describe how a converter is started.

Ans. There are several methods any one of which may be employed, the choice in any given case depending upon which of them may best be followed under the existing conditions.

If it be found advisable to start the converter with direct current, the same connections would be made between the source of the direct current and the armature terminals on the commutator side of the converter as would be the case were a direct current shunt motor of considerable size to be started; this naturally means that a starting rheostat and a circuit breaker will be introduced in the armature circuit.

The shunt field winding alone is used, and this part of the wiring may be made permanent if, as is usually the case, the same source of direct current is used normally for separate field excitation.

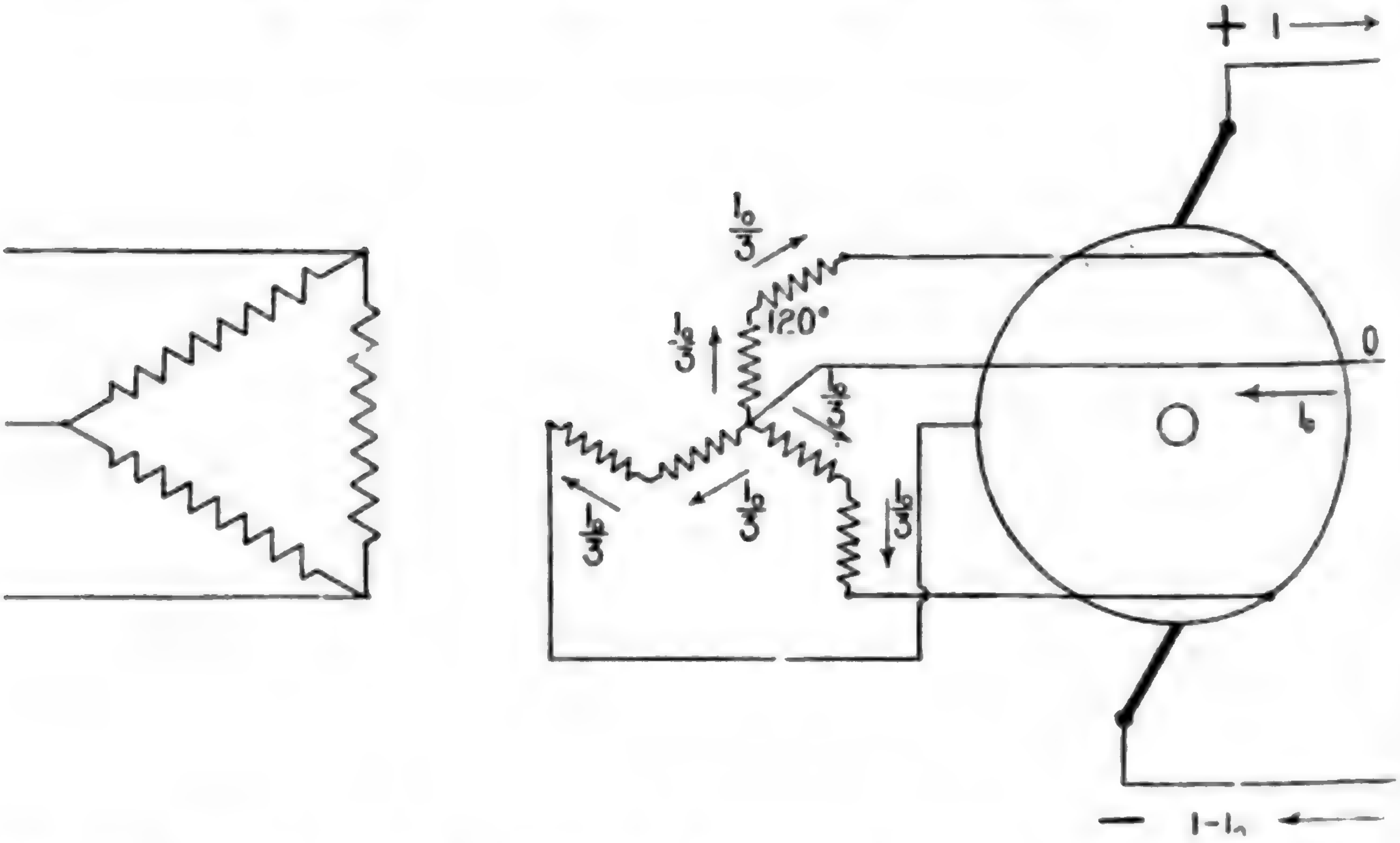


FIG. 2,871.—Wiring diagram of three wire synchronous converter with distributed Y secondary. This system eliminates the flux distortion due to the unbalanced direct current in the neutral. Two separate interconnected windings are used for each leg of the Y. The unbalanced neutral current flowing in this system may be compared in action to the effect of a magnetizing current in a transformer. The effect of the main transformer currents in the primary and secondary is balanced with regard to the flux in the transformer core, which depends upon the magnetic current. When a direct current is passed through the transformer, unless the fluxes produced by the same neutralize one another, its effect on the transformer iron varies as the magnetizing current. For example, assume a transformer having a normal ampere capacity of 100 and, approximately, 6 amperes magnetizing current, and assume that three such transformers are used with Y connected secondaries for operating a synchronous converter connected to a three wire Edison system. Allowing 25 per cent. unbalancing, the current will divide equally among the three legs giving 8.33 amperes per leg, which is more than the normal magnetizing current. The loss due to this current is, however, inappreciable, but the increased core losses may be considerable. If a distributed winding be used, the direct current flows in the opposite direction, around the halves of each core thus entirely neutralizing the flux distortion. Whether the straight Y connection is to be used is merely a question of balancing the increased core loss of the straight Y connection against the increased copper loss and the greater cost of the interconnected Y system. The straight Y connection is much simpler, and it would be quite permissible to use it for transformers of small capacities where the direct current circulating in the neutral is less than 30 per cent. of the rated transformer current.

The direct current may be derived from a storage battery, from a separate converter, or from a motor generator set installed in the substation for the purpose.

An adjustable rheostat will, of course, be connected in the field circuit for regulation. Before starting the converter, however, it is necessary to do certain wiring between the terminals on the collector side of the machine and the alternating current supply wires, in order that the change over from direct current motive power to alternating current motive power may be made when the proper phase relations are established between the alternating current in the supply wires and the alternating current in the armature winding of the converter.

In order that proper phase relations exist, the armature of the converter must rotate at such a speed that each coil thereon passes its proper reversal point at the same time as the alternating current reverses in the supply wires. This speed may be calculated by doubling the frequency of the supply current and then dividing by the number of pole pieces on the converter, but a far more accurate method of judging when the converter is in step or in synchronism with the supply current consists in employing incandescent lamps as shown in fig. 2,872.

Ques. How is a polyphase converter started with alternating current?

Ans. This may be done by applying the alternating pressure directly to the collector rings while the armature is at rest. There need be no field excitation; in fact the field windings on the separate pole pieces should be disconnected from each other before the alternating voltage is applied to the armature, else a high voltage will be induced in the field windings which may prove injurious to their insulation. The passage of the alternating current through the armature winding produces a magnetic field that rotates about the armature core, and induces in the pole pieces eddy currents, which, reacting on the armature, exert a sufficient torque to start the converter from rest and cause it to speed up to synchronism.

Ques. How much alternating current is required to start a polyphase converter?

Ans. About 100 per cent. more than that required for full load.

Ques. How may this starting current be reduced?

Ans. Transformers may be switched into circuit temporarily to reduce the line wire voltage until the speed become normal.

In conjunction with this method, the method of synchronizing shown in fig. 2,872 may be used, thus, in starting, there is an alternating current between the brushes which pulsates very rapidly, but when synchronism

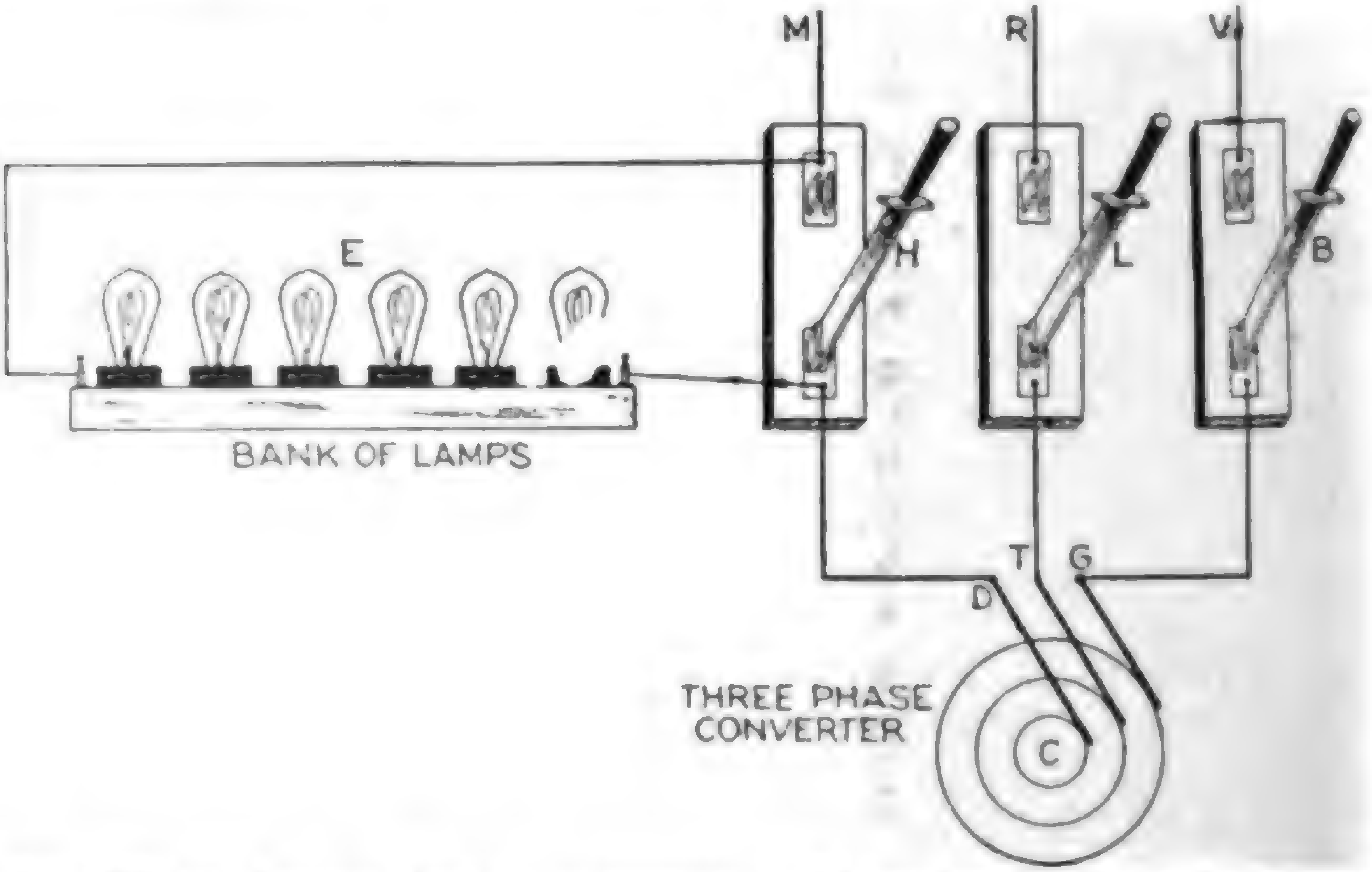


FIG. 2,872.—Wiring diagram showing arrangement of incandescent lamps for determining the proper phase relations in starting a rotary converter. The alternating current side of a three phase converter is shown at C. The three brushes, D, T and G pressing on its collector rings are joined in order to the three single pole switches H, L and B which can be made to connect with the respective wires M, R, and V, of the alternating current supply circuit. Across one of the outside switches, H, for example, a number of incandescent lamps are joined in series as indicated at E, while the three pole switch (not shown) in the main circuit, between the alternator and the single pole switches is open. If then the main switch just mentioned and the middle switch L be both closed, and the armature of the alternator be brought up to normal speed by running it as a direct current motor, the lamps at E will light up and darken in rapid succession; the lighting and darkening of the lamps will continue until, by a proper adjustment of the speed, the correct phase relations be established between the alternating current in the supply circuit and the alternating current developed in the armature of the converter. As this condition is approached, the intervals between the successuve lighting up and darkening of the lamps will increase until they remain perperfectly dark. There is then no difference of pressure between the supply circuit M R V and the rotary converter armature circuit, so the source of the direct current may at that instant be disconnected from the machine, and the switches H and B, closed. If the change over has been accomplished before the phase relations of the two circuits differed, the converter will at once conform itself to the supply circuit and run thereon as a synchronous motor without further trouble. The opening of the direct current circuit and the closing of the alternating current supply circuit may be done by hand, but preferably by employing a device that will automatically trip the circuit breaker in the direct current circuit at the instant the switches in the alternating current circuit are closed.

is approached, the pulsations become less rapid until finally with the converter in step with the alternator the pulsations entirely disappear.

The light given by the lamps thus connected indicates accurately the condition of affairs at any one time, varying from a rapidly fluctuating light at the beginning to one of constant brilliancy at synchronism.

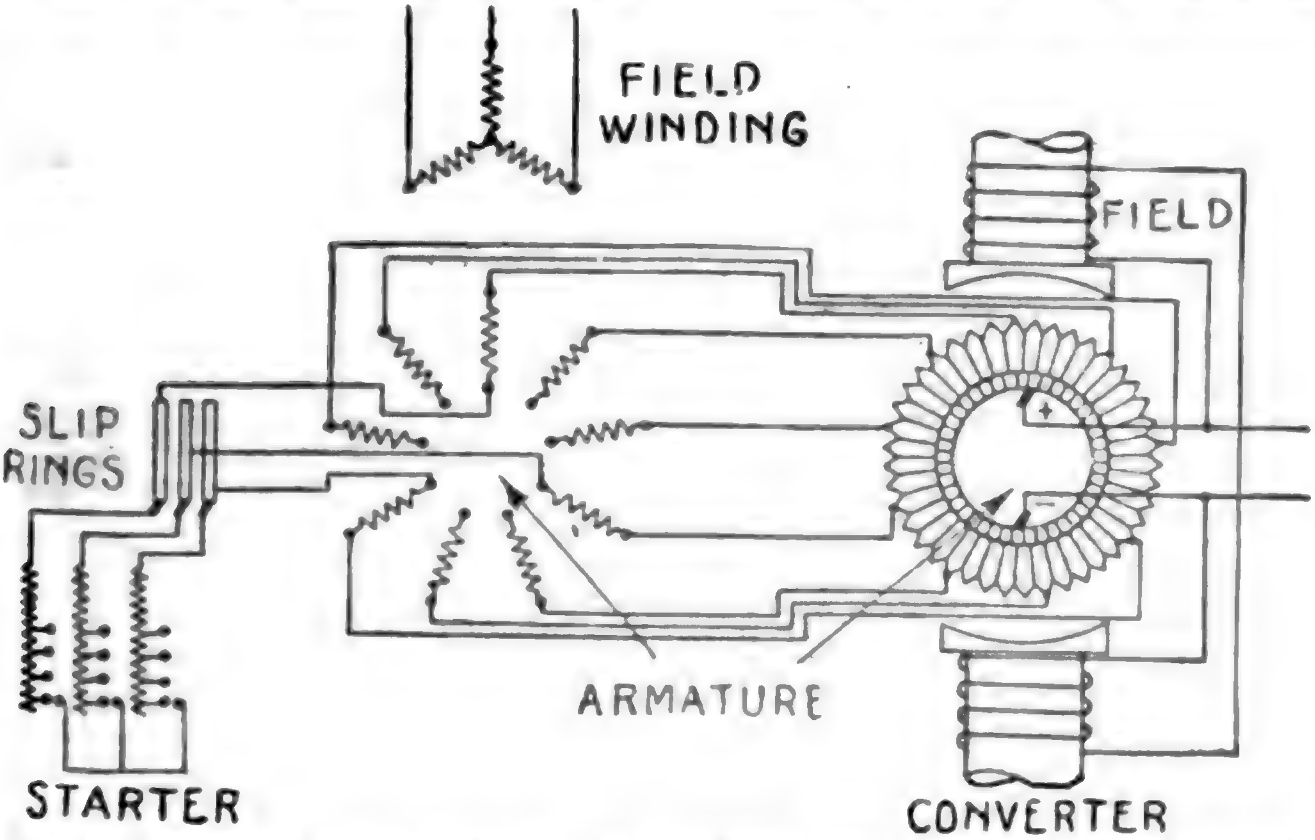


FIG. 2,873.—Diagram of motor converter. This machine which is only to be used for converting from alternating to direct current, consists of an ordinary induction motor with phase wound armature, and a dynamo. The revolving parts of both machines are mounted on the same shaft and from the figure it is seen that the armature of the motor and the armature of the dynamo are also electrically connected. The motor converter is a synchronous machine, but the dynamo receives the current from the armature of the motor at a frequency much reduced from that impressed upon the field winding of the motor. Assuming that the motor and the converter have the same number of pole, the motor will rotate at a speed corresponding to one-half the frequency of the supply circuit. The motor will operate half as a motor and half as a transformer, and the converter, half as a dynamo and half as a synchronous converter, in that one-half of the electrical energy supplied to the motor will be converted into mechanical power for driving the converter, while the other one-half is transferred to the secondary motor windings and thereby to the converter armature in the form of electrical power. The capacity of the motor is theoretically only half what it would be if it were to convert the whole of the electrical energy into mechanical power because the rating depends upon the speed of the rotating field and not on that of the rotor. If the two machines have a different number of pole, or are connected to run at different speeds, the division of power is at a different but constant ratio. The machine starts up as an ordinary polyphase induction motor and the field of the converter is built up as though it were an ordinary dynamo. Motor converters are occasionally used on high frequency systems, as their commutating component is of half frequency, and thus permits better commutator design than a high frequency converter. The advantage of this type of machine is that for phase control it requires no extra reactive coils, the motor itself having sufficient reactance. It is, however, larger than standard converters, but smaller than motor generators, as half the power is converted in each machine. Its efficiency is less than for synchronous converters, and the danger of reaching double speed in case of a short circuit on the direct current side is very great. It has been used abroad to some extent for 60 cycle work, in preference to synchronous converters, but with the present reliable design of 60 cycle converters, and the general use of 25 cycles, where severe service conditions are met, as in railroading, motor converters should not be recommended.

Ques. If the armature of the starting motor have a starting resistance, how must this be connected?

Ans. It should be connected in series with the armature inductors before the alternating voltage is applied.

As the motor increases in speed, the starting resistance is gradually short circuited until it is entirely cut out of circuit.

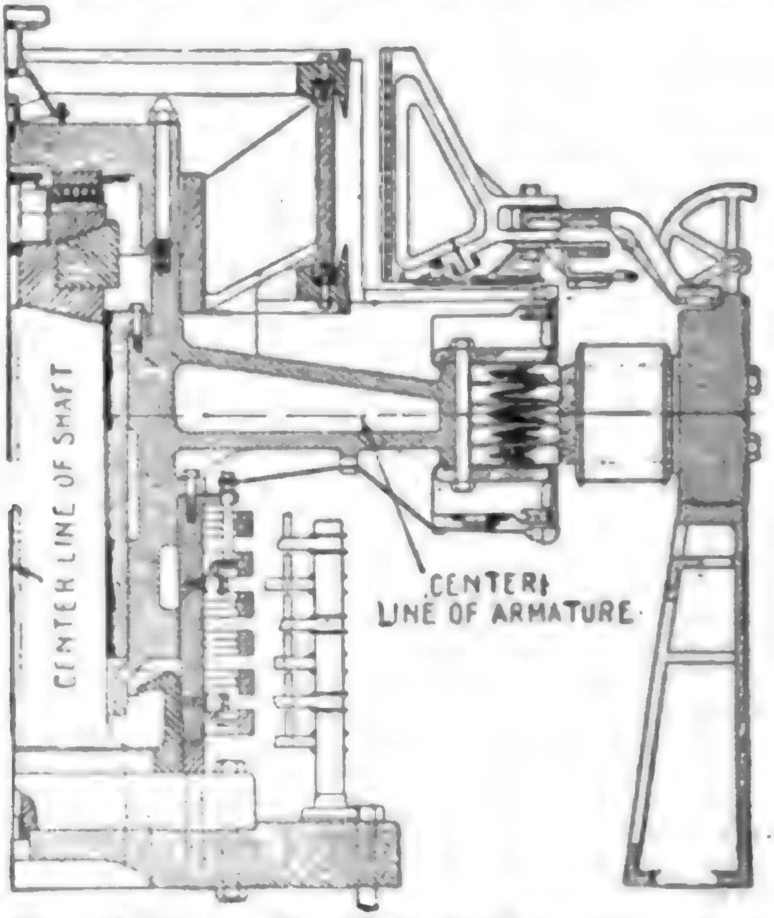


FIG. 2,874.—Sectional view of General Electric vertical synchronous converter. In this construction, the field frame carrying the poles is mounted on cast iron pedestals and is split vertically. This allows the two halves of the frame to be separated for inspection or repairs of the armature. The armature, including commutator and collector rings, is mounted on a vertical stationary shaft, which is rigidly supported from the foundation. The thrust of the armature is carried on a roller bearing attached to the top of the shaft and upper side of the armature spider. The under side of the lower plate of the roller bearing is made spherical and fits into a corresponding spherical cup on the end of the shaft, making the bearing self aligning. The armature spider has a babbited sleeve along the fit of the vertical shaft, which acts as a guide bearing and has to take only the thrust due to the unbalancing effect of the rotating parts. A circulating pump furnishes oil to the roller bearing, the oil draining off through the guide bearing. A marked advantage of this type of construction is the accessibility of the commutator for adjustment of the brushes, etc., as there is no pit or pedestal bearing to interfere.

NOTE.—Some converters are provided with a small induction motor for starting mounted on an iron bracket cast in the converter frame, and whose shaft is keyed to that of the converter. Allowing for a certain amount of slip in the induction motor, the field of this machine must possess a less number of magnet poles than the converter in order to enable the latter machine to be brought to full synchronism. To start the induction motor, it is simply necessary to apply to its field terminals the proper alternating voltage. The bracket, and therefore the motor, is usually mounted outside the armature bearing on the collector side of the converter.

Ques. Describe the usual wiring for the installation of a rotary converter in a sub-station.

Ans. Commencing at the entrance of the high pressure cables, first there is the wiring for the lightning arresters, then for

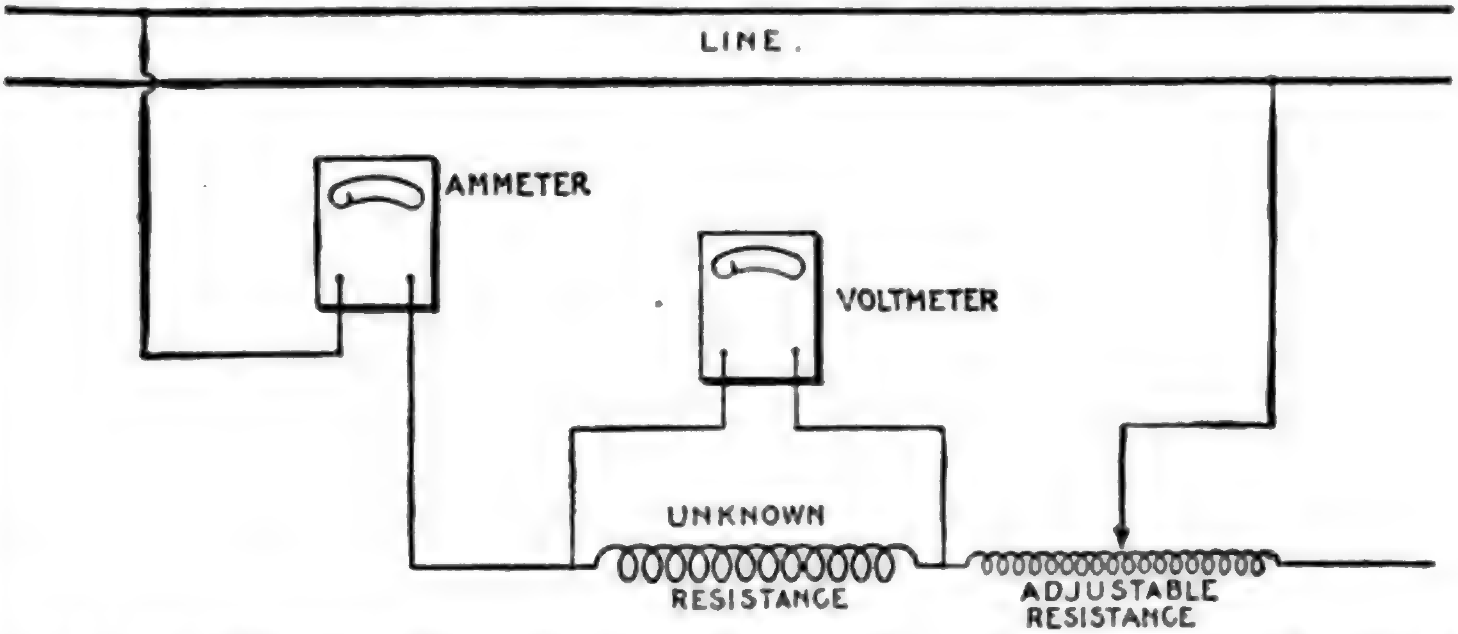
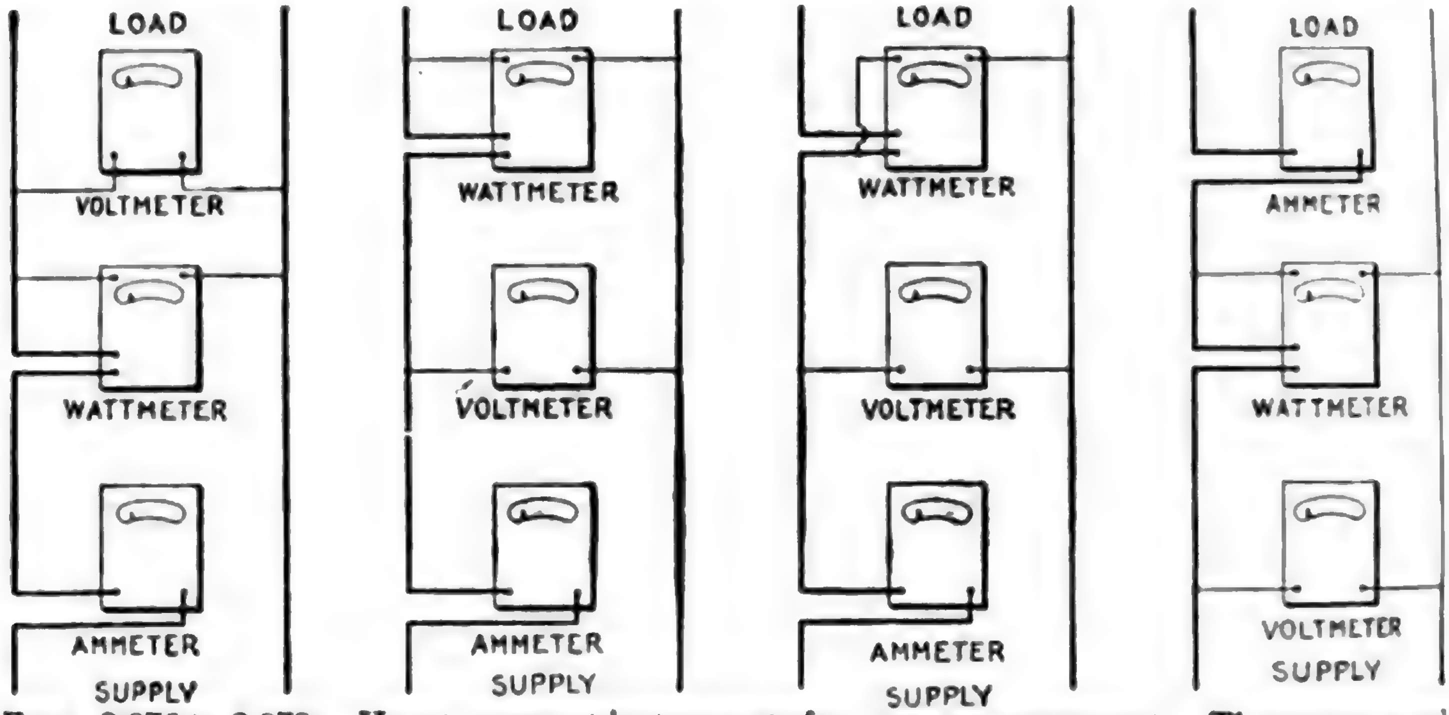


FIG. 2,875.—Resistance measurement by "drop" method. The circuit whose resistance is to be measured, is connected in series with an ammeter and an adjustable resistance to vary the flow of current. A voltmeter is connected directly across the terminals of the resistance to be measured, as shown in the figure. According to Ohm's law $I = E \div R$, from which, $R = E \div I$. If then the current flowing in the circuit through the unknown resistance be measured, and also the drop or difference of pressure, the resistance can be calculated by above formula. In order to secure accurate determination of the resistance such value of current must be used as will give large deflections of the needle on the instruments employed. A number of independent readings should be taken with some variation of the current and necessarily a corresponding variation in voltage. The resistance should then be figured from each set of readings and the average of all readings taken for the correct resistance. Great care must be taken, however, in the readings, and the instruments must be fairly accurate. For example, suppose that the combined instrument error and the error of the reading in the voltmeter should be 1 per cent., the reading being high, while the corresponding error of the ammeter is 1 per cent. low. This would cause an error of approximately 2 per cent. in the reading of the resistance. In making careful measurements of the resistance, it is also necessary to determine the temperature of the resistance being measured, as the resistance of copper increases approximately .4 of 1 per cent. for each degree rise in temperature. Use is made of this fact for determining the increase in temperature of a piece of apparatus when operating under load. The resistance of the apparatus at some known temperature is measured, this being called the cold resistance of the apparatus. At the end of the temperature test the hot resistance is taken. Assume the resistance has increased by 15 per cent. This would indicate a rise in temperature of 37½ degrees above the original or cold temperature of the apparatus. Suppose then that in measuring the cold resistance, results are obtained which are 2 per cent. low, and that in measuring the hot resistance, there be 2 per cent error in the opposite direction. This would mean that a total error of 4 per cent. had been made in the difference between the hot and cold resistances, or an error of 10 degrees. The correct rise in temperature is, therefore, about 27½ instead of 37½ degrees. In other words, an error of 2 per cent. in measuring each resistance has caused an error of approximately 36½ per cent. in the measurement of the rise in temperature. The constant .4 which has been used above is only approximate and should not be used for exact work. For detail instructions of making calculations of resistance and termperature, see "Standardization Rules of the A. I. E E."



FIGS. 2,876 to 2,879.—How to connect instruments for power measurement. There are several ways of connecting an ammeter, voltmeter and wattmeter in the circuit for the measurement of power. A few of the methods are discussed below. With some of the connections it is necessary to correct the readings of the wattmeter for the losses in the coil, or coils, of the wattmeter, or for losses in ammeter or voltmeter. This is necessary since the instruments may be so connected that the wattmeter not only measures the load but includes in its indications some of the instrument losses. If the load measured be small, or considerable accuracy is required, these instrument losses may be calculated as follows: Loss in pressure coil is $E^2 \div R$, in which E is the voltage at the terminals of the pressure coil and R is the resistance. Loss in current coil is $I^2 R$ in which I is the current flowing and R the resistance of the current coil. In general let E_v = voltage across terminals of the voltmeter; E_w = voltage across the terminals of the pressure coil of the wattmeter; I_w = current through current coil of wattmeter; I_a = current through current coil of ammeter; R_v = resistance of pressure coil of voltmeter; R_w = resistance of pressure coil of wattmeter; R^1_w = resistance of current coil of wattmeter; R_a = resistance of current coil of ammeter. Then the losses in the various coils will be as follows: $E^2_v \div R_v$ = loss in pressure coil of voltmeter. $E^2_w \div R_w$ = loss in pressure coil of wattmeter. $I^2_w R^1_w$ = loss in current coil of wattmeter. $I^2_a R_a$ = loss in current coil of ammeter. If connection be made as in fig. 2,876, the correct power of the circuit will be the wattmeter reading $W - (E^2_v \div R_v + E^2_w \div R_w)$ in which $E_v = E_w$. In fig. 2,877, the power is $W - E^2_w \div R_w$. In fig. 2,878, the power is $W - I^2_w R^1_w$, or the correct power is the wattmeter reading minus the loss in the current coil of the wattmeter. In fig. 2,879, the power is $W - (E^2_w \div R_w + I^2_a R_a)$. The usual method of connection is either as in fig. 2,876 or fig. 2,877. In either case the current reading is that of the load plus the currents in the pressure coils of the voltmeter and wattmeter. Unless the current being measured, however, is very small, or extreme accuracy is desired, it is unnecessary to correct ammeter readings. In fig. 2,877 a small error is introduced due to the fact that the actual voltage applied to the load is that given by the voltmeter minus the small drop in voltage through the current coil of the wattmeter. If an accurate measure of the current in connection with the power consumed by the load be required, the connections shown in fig. 2,879 are used, and if extreme accuracy is required, the wattmeter reading is reduced by the losses in the ammeter and in the pressure coil of the wattmeter. The loss in the pressure coil of a wattmeter or voltmeter may be as high as 12 or 15 watts at 220 volts. The loss in the current coil of a wattmeter with 10 amperes flowing may be 6 or 8 watts. It can be easily seen that if the core or copper losses of small transformers are being measured, it is quite necessary to correct the wattmeter readings, for the instrument losses. In measuring the losses of a 25 or 50 H.P. induction motor, the instrument losses may be neglected. A careful study of the above will show when it becomes necessary to correct for instrument losses and the method of making these corrections. Connections are seldom used which make it necessary to correct for the losses in the current coils of either ammeter or wattmeter, as the losses vary with the change in the current. On the other hand, the voltages generally used are fairly constant at 110 or 220, and when the losses of the pressure coils at these voltages have once been calculated, the necessary instrument correction can be readily made.

the connection in circuit of the high tension switching devices, from which the conductors are led to bus bars, and thence to the step down transformers.

On a three phase system the transformers should be joined in delta connection, as a considerable advantage is thereby gained over the star connection, in that should one of the transformers become defective, the remaining two will carry the load without change except more or less additional heating. Between the transformers and rotary converter the circuits should be as short and simple as possible, switches, fuses, and other instruments being entirely excluded. The direct current from the converter is led to the direct current switchboard, and from there distributed to the feeder circuits.

WATTMETER ERROR FOR A LOAD OF 1,000 VOLT-AMPERES

(For a lag of 1 degree in the pressure coil)

Power factor	True watts	Error	Error of indication in per cent. of true value
1.	1,000	.3	0.03
.9	900	7.6	0.85
.8	800	10.5	1.31
.7	700	12.5	1.78
.6	600	13.9	2.32
.5	500	15.1	3.02
.4	400	15.9	3.98
.3	300	16.6	5.54
.2	200	17.1	8.55
.1	100	17.3	1.73

NOTE.—In the iron vane type instrument when used as a wattmeter, the current of the series coil always remains in perfect phase with the current of the circuit, provided series transformers are not introduced. The error, then, is entirely due to the lag of the current in the pressure coil, and this error in high power factor is exceedingly small, increasing as the power factor decreases. In the above table it should be noted that the value of the error as distinguished from the per cent. of error, instead of indefinitely increasing as the power factor diminishes, rapidly attains a maximum value which is less than 2 per cent. of the power delivered under the same current and without inductance. It should also be noted that the above tabulation is on the assumption of a lag of 1 degree in the pressure coil. The actual lag in Wagner instruments for instance, is approximately .085 of a degree, and the error due to the lag of the pressure coil in Wagner instruments is, therefore, proportionally reduced from the figures shown in the above tabulation.

Ques. In large sub-stations containing several rotary converters how are they operated?

Ans. Frequently they are installed to receive their respective currents from the same set of bus bars; that is, they may be operated as alternating current motors in parallel. They are also frequently operated independently from single bus bars, but very seldom in series with each other.

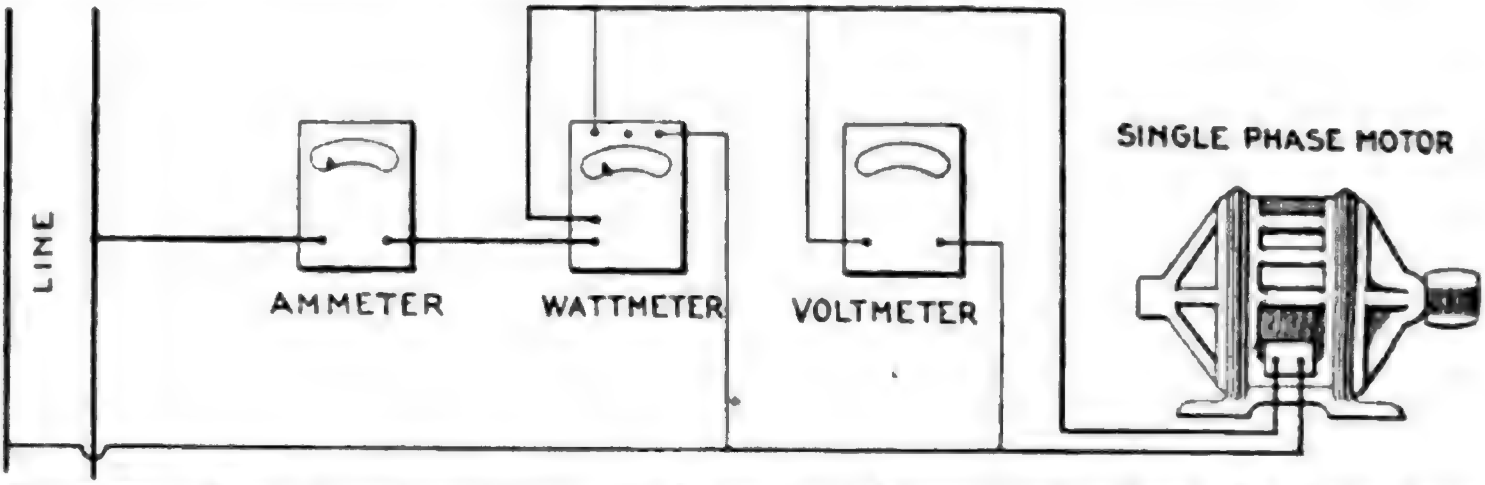


FIG. 2,880.—Single phase motor test. In this method of measuring the input of a single phase motor of any type, the ammeter, voltmeter and wattmeter are connected as shown in the illustration. The ammeter measures the current flowing through the motor, the voltmeter, the pressure across the terminals of the motor, and the wattmeter the total power which flows through the motor circuit. With the connections as shown, the wattmeter would also measure the slight losses in the voltmeter and the pressure coil of the wattmeter, but for motors of ¼ H.P. and larger, this loss is so small that it may be neglected. The power factor may be calculated by dividing the true watts as indicated by the wattmeter, by the product of the volts and amperes.

Ques. How may the direct current circuit be connected?

Ans. In parallel.

NOTE.—In motor testing, by the methods illustrated in the accompanying cuts, it is assumed that the motor is loaded in the ordinary way by belting or direct connecting the motor to some form of load, and that the object is to determine whether the motor is over or under loaded, and approximately what per cent. of full load it is carrying. All commercial motors have name plates, giving the rating of the motor and the full load current in amperes. Hence the per cent. of load carried can be determined approximately by measuring the current input and the voltage. If an efficiency test of the apparatus be required, it becomes necessary to use some form of absorption by dynamometer, such as a Prony or other form of brake. The output of the motor can then be determined from the brake readings. The scope of the present treatment is, however, too limited to go into the subject of different methods of measuring the output of the apparatus, and is confined rather to methods of measuring current input, voltage, and watts. The accuracy of all tests is obviously dependent upon the accuracy of the instruments employed. Before accepting the result obtained by any test, especially under light or no load, correction should be made for wattmeter error. See table of wattmeter error on page 2,075.

Ques. What provision should be made against interruption of service in sub-stations?

Ans. There should be one reserve rotary converter to every three or four converters actually required.

Ques. Why does a rotary converter operate with greater efficiency, and require less attention than does a dynamo of the same output?

Ans. There is less friction, and less armature resistance,

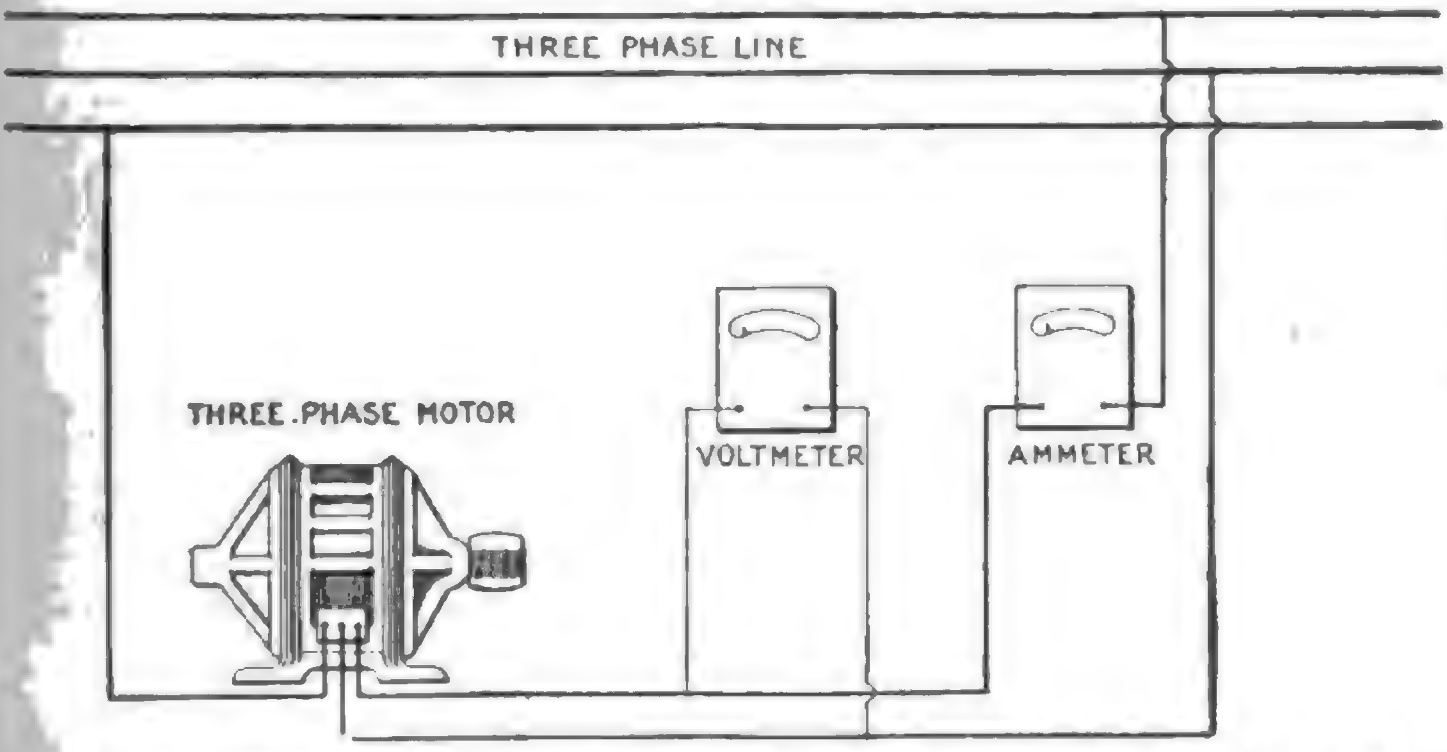


FIG. 2,881.—Three phase motor test; voltmeter and ammeter method. If it be desired to determine the approximate load on a three phase motor, this may be done by means of the connections as shown in the figure, and the current through one of the three lines and the voltage across the phase measured. If the voltage be approximately the rated voltage of the motor and the amperes the rated current of the motor (as noted on the name plate) it may be assumed that the motor is carrying approximately full load. If, on the other hand, the amperes show much in excess of full load rating, the motor is carrying an overload. The heat generated in the copper varies as the square of the current. That generated in the iron varies anywhere from the 1.6 power, to the square. This method is very convenient if a wattmeter be not available, although, it is, of course, of no value for the determination of the efficiency or power factor of the apparatus. This method gives fairly accurate results, providing the load on the three phases of the motor be fairly well balanced. If there be much difference, however, in the voltage of the three phases, the ammeter should be switched from one circuit to another, and the current measured in each phase. If the motor be very lightly loaded and the voltage of the different phases vary by 2 or 3 per cent., the current in the three legs of the circuit will vary 20 to 30 per cent.

the latter because the alternating current at certain portions of each revolution passes directly to the commutator bars witho traversing the entire armature winding as it does in a dynamo; there is no distortion of the field and consequently no sparking, or shifting of the brushes, since the armature reaction resulting from the current fed into the machine and that due to the current generated in the armature completely neutralizes each other.

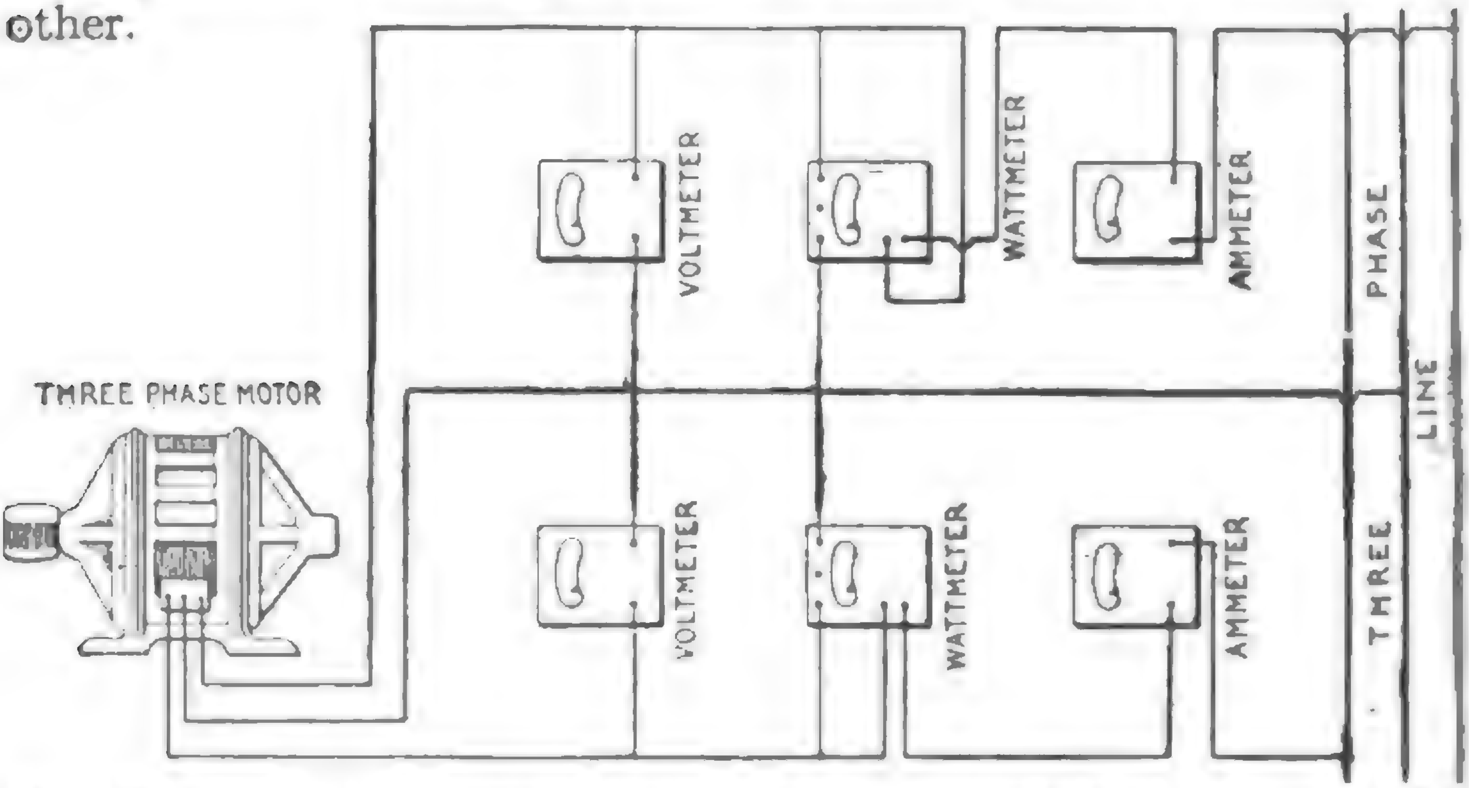


FIG. 2,882.—Three phase motor test by the two wattmeter method. If an accurate test of a three phase motor be required, it is necessary to use the method here indicated. Assume the motor to be loaded with a brake so that its output can be determined. This method gives correct results even with considerable unbalancing in the voltages of the three phases. With the connections as shown, the sum of the two wattmeter readings gives the total power in the circuit. Neither meter by itself measures the power in any one of the three phases. In fact, with light load one of the meters will probably give a negative reading, and it will then be necessary to either reverse its current or pressure leads in order that the deflection may be noted. In such cases the algebraic sums of the two readings must be taken. In other words, if one read plus 500 watts and the other, minus 300 watts, the total power in the circuit will be 500 minus 300, or 200 watts. As the load comes on, the readings of the instrument which gave the negative deflection will decrease until the reading drops to zero, and it will then be necessary to again reverse the pressure leads on this wattmeter. Thereafter the readings of both instruments will be positive, and the numerical sum of the two should be taken as the measurement of the load. If one set of the instruments be removed from the circuit, the reading of the remaining wattmeter will have no meaning. As stated above, it will not indicate the power under these conditions in any one phase of the circuit. The power factor is obtained by dividing the actual watts input by the product of the average of the voltmeter readings × the average of the ampere readings × 1.73.

Ques. What electrical difficulty is experienced with a rotary converter?

Ans. Regulation of the direct current voltage.

Ques. How is this done?

Ans. It can be maintained constant only by preserving uniform conditions of inductance in the alternating current circuit, and uniform conditions in the alternator.

While changes in either of these may be compensated to a certain extent by adjustment of the field strength of the converter, they cannot be entirely neutralized in this manner; it is therefore necessary that both the line circuit and the alternator be given attention if the best results are to be obtained from the converter.

Ques. What mechanical difficulty is experienced with rotary converters?

Ans. Hunting.

Ques. What is the cause of this?

Ans. It is due to a variation in frequency.

The inertia of the converter armature tends to maintain a constant speed; variations in the frequency of the supply circuit will cause a displacement of phase between the current in the armature and that in the line wires, which displacement, however, the synchronizing current strives to decrease. The synchronizing current, although beneficial in remedying the trouble after it occurs, exerts but little effort in preventing it, and many attempts have been made to devise a plan to eliminate this trouble.

NOTE.—Three phase motor test; polyphase wattmeter method. This is identical with the test of fig. 2,882, except that the wattmeter itself combines the movement of the two wattmeters. Otherwise the method of making the measurements is identical. If the power factor be known to be less than 50 per cent., connect one movement so as to give a positive deflection; then disconnect movement one and connect movement two so as to give a positive deflection. Then reverse either the pressure or current leads of the movement, giving the smaller deflection, leaving the remaining movement with the original connections. The readings now obtained will be the correct total watts delivered to the motor. If the power factor be known to be over 50 per cent., the same methods should be employed, except that both movements should be independently connected to give positive readings. An unloaded induction motor has a power factor of less than 50 per cent., and may, therefore, be used as above for determining the correct connections. For a better understanding of the reasons for the above method of procedure, the explanation of the two wattmeter method, fig. 2,882, should be read. The power factor may be calculated as explained under fig. 2,882. Connect as shown in fig. 2,882. The following check on connection may be made. Let the polyphase induction motor run idle, that is, with no load. The motor will then operate with a power factor less than 50 per cent. The polyphase meter should give a positive indication, but if each movement be tried separately one will be found to give a negative reading, the other movement will give a positive reading. This can be done by disconnecting one of the pressure leads from the binding post of one movement. When the power factor is above 50 per cent. then both movements will give positive deflection.

Ques. What are the methods employed to prevent hunting?

Ans. 1, the employment of a strongly magnetized field relative to that developed by the armature; 2, a heavy flywheel effect in the converter; 3, the increasing of the inductance of the armature by sinking the windings thereon in deep slots in the core, the slots being provided with extended heads; and 4, the employment of damping devices or amortisseur winding on the pole pieces of the converter.

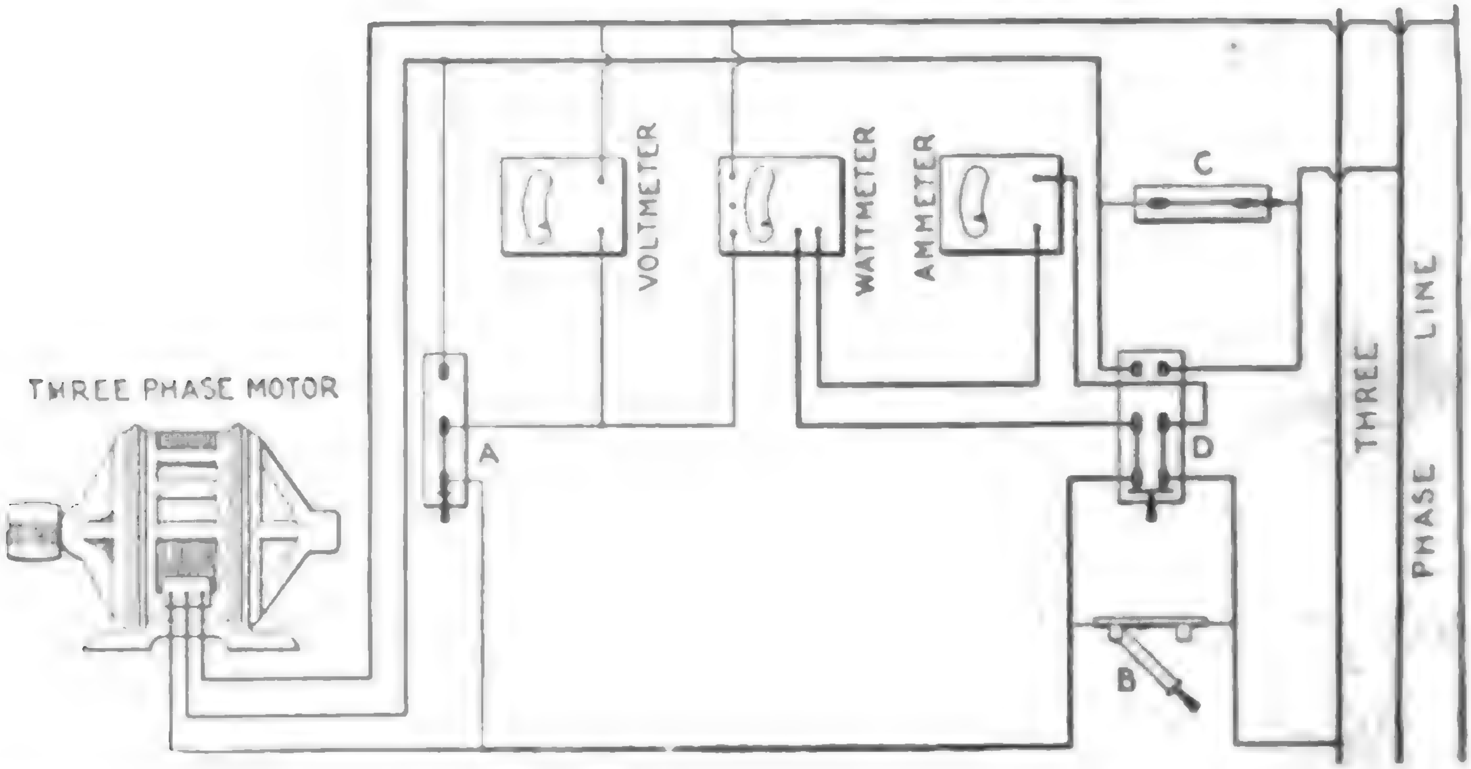


FIG. 2,883.—Three phase motor test; one wattmeter method. This method is equivalent to the two wattmeter method with the following difference. A single voltmeter (as shown above) with a switch, A, can be used to connect the voltmeter across either one of the two phases. Three switches, B, C and D, are employed for changing the connection of the ammeter and wattmeter in either one of the two lines. With the switches B and D in the position shown, the ammeter and wattmeter series coils are connected in the left hand line. The switch C must be closed under these conditions in order to have the middle line closed. Another reading should then be taken before any change of load has occurred, with switch A thrown to the right, switch B closed, switch D thrown to the right and switch C opened. The ammeter and the current coil of the wattmeter will then be connected to the middle line of the motor. In order to prevent any interruption of the circuit, the switches B, D and C should be operated in the order given above. With very light load on the motor the wattmeter will probably give a negative deflection in one phase or the other, and it will be necessary to reverse its connections before taking the readings. For this purpose a double pole, double throw switch is sometimes inserted in the circuit of the pressure coil of the wattmeter so that the indications can be reversed without disturbing any of the connections. It is suggested, before undertaking this test, that the instructions for test by the two wattmeter and by the polyphase wattmeter methods be read.

Ques. What method is the best?

Ans. The damping method.

The devices employed for the purpose are usually copper shields placed between or around the pole pieces, although in some converters the copper is embedded in the poles, and in others it is made simply to surround a portion of the pole tips.

In any case its action is as follows: The armature rotating at a variable speed has a field developed therein which is assumed to be also rotating at a variable speed; the magnetism of this rotary field induces currents in the copper which, however, react on the armature and oppose any tendency toward a further shifting of the magnetism in the armature and therefore prevent the development of additional currents in the copper. Since copper is of low resistance, the induced currents are sufficient in strength to thus dampen any tendency toward phase displacement, and so exert a steadying influence upon the installation as a whole.

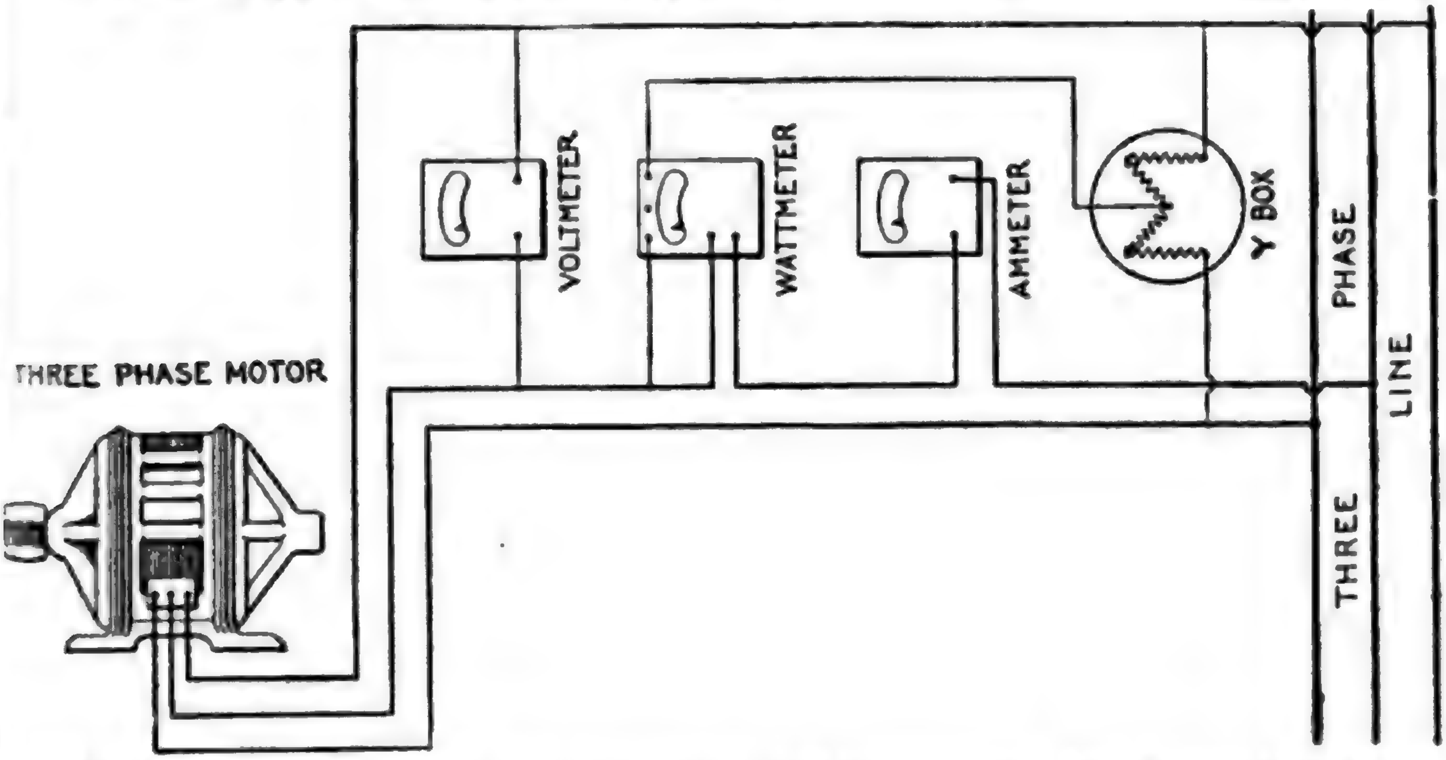


FIG. 2,884.—Three phase motor, one wattmeter and Y box method. This method is of service, only, provided the voltages of the three phases are the same. A slight variation of the voltage of the different phases may cause a very large error in the readings of the wattmeter, and inasmuch as the voltage of all commercial three phase circuits is more or less unbalanced, this method is not to be recommended for motor testing. With balanced voltage in all three phases, the power is that indicated by the wattmeter, multiplied by three. Power factor may be calculated as before.

Electrical Measuring Instruments.—In the manufacture of most measuring instruments, the graduations of the scale are made at the factory, by comparing the deflections of the pointer with voltages as measured on standard apparatus. The voltmeters in most common use have capacities of 5, 15, 75, 150, 300, 500 and 750 volts each, although in the measurement of very low resistances such as those of armatures, heavy cables, or bus bars, voltmeters having capacities as low as .02 volt are employed.

The difference between the design of direct current voltmeters of different capacities lies simply in the high resistance joined in series with the fine wire coil. This resistance is usuall about 100 ohms per volt capacity of the meter, and is compose of fine silk covered copper wire wound non-inductively on wooden spool.

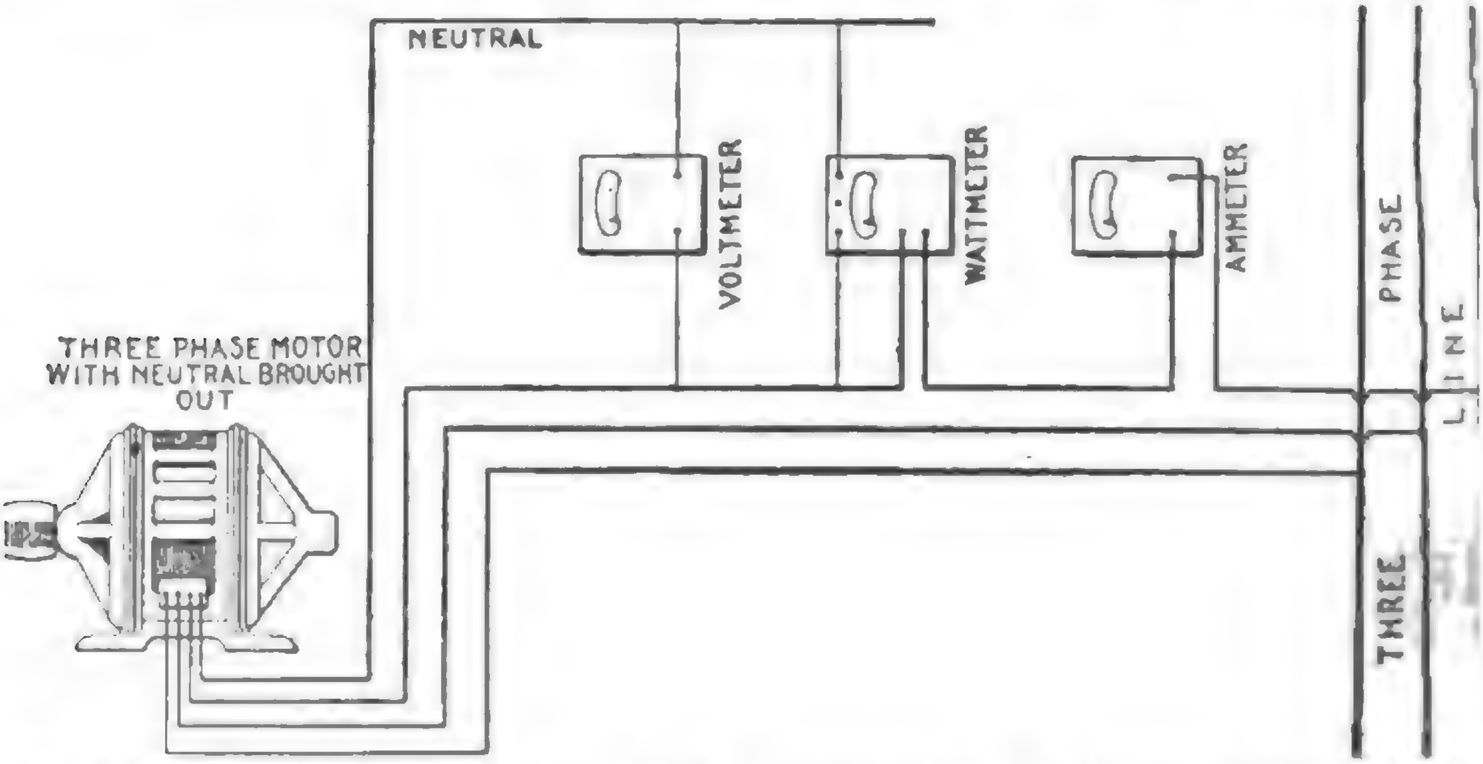


Fig. 2,885.—Test of three phase motor with neutral brought out; single wattmeter method Some star connected motors have the connection brought out from the neutral of th winding. In this case the circuit may be connected, as here shown. The voltmeter nov measures voltage between the neutral and one of the lines, and the wattmeter the powe in one of the three phases of the motor. Therefore, the total power taken by the mot will be three times the wattmeter readings. By this method, just as accurate result can be obtained as with the two wattmeter method. The power factor will be the indi cated watts divided by the product of the indicated amperes and volts.

In the operation of an instrument, if the pointer when de flected do not readily come to a position of rest owing t friction in the moving parts, it may be aided in this respect b gently tapping the case of the instrument with the hand; this will often enable the obstruction, if not of a serious nature, to be overcome and an accurate reading to be obtained.

Ques. Describe a two scale voltmeter.

Ans. In this type of instrument, one scale is for low voltage

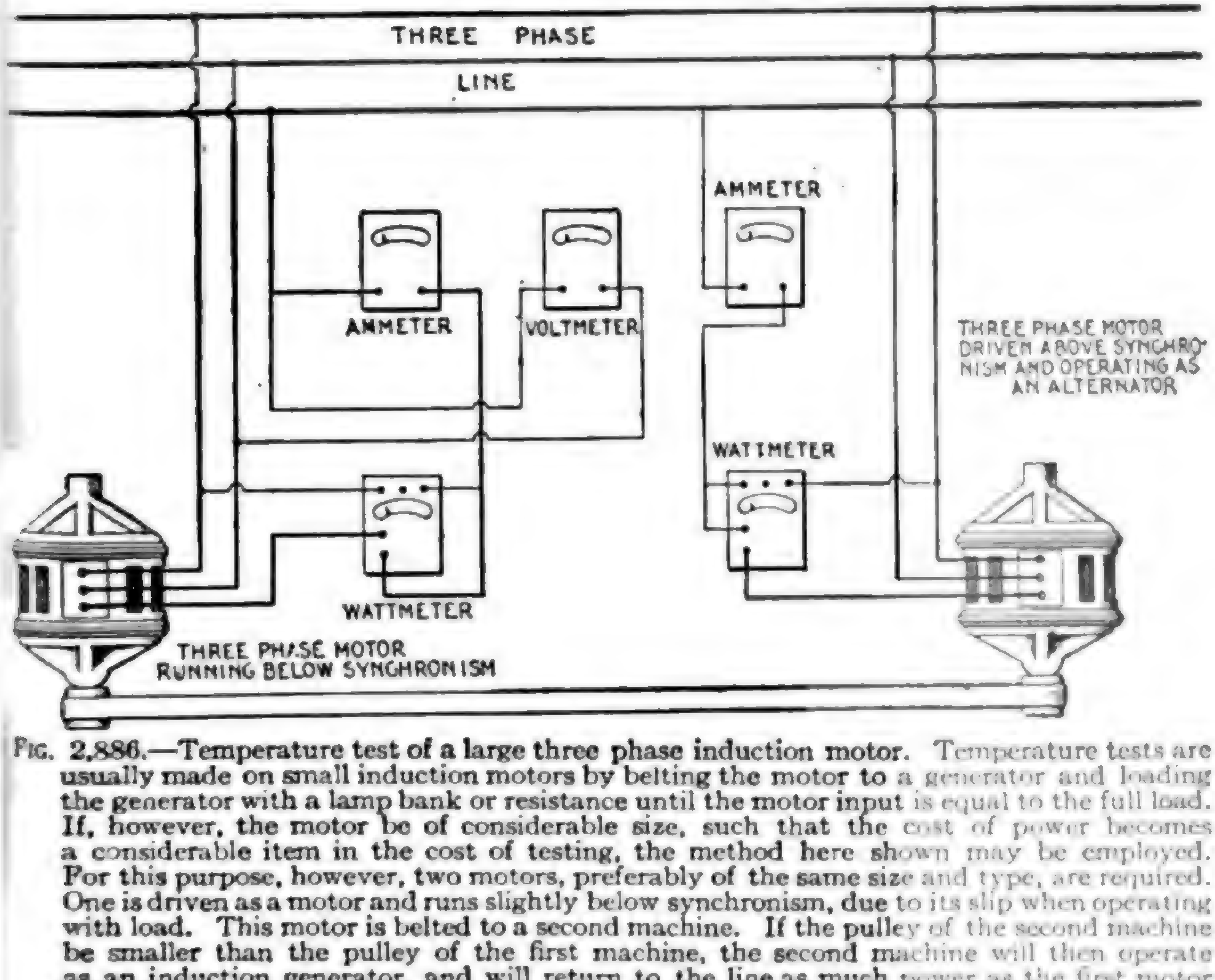

THREE PHASE
LINE
AMMETER
AMMETER
VOLTMETER
THREE PHASE MOTOR DRIVEN ABOVE SYNCHRONISM AND OPERATING AS AN ALTERNATOR
WATTMETER
WATTMETER
THREE PHASE MOTOR RUNNING BELOW SYNCHRONISM

FIG. 2,886.—**Temperature test of a large three phase induction motor.** Temperature tests are usually made on small induction motors by belting the motor to a generator and loading the generator with a lamp bank or resistance until the motor input is equal to the full load. If, however, the motor be of considerable size, such that the cost of power becomes a considerable item in the cost of testing, the method here shown may be employed. For this purpose, however, two motors, preferably of the same size and type, are required. One is driven as a motor and runs slightly below synchronism, due to its slip when operating with load. This motor is belted to a second machine. If the pulley of the second machine be smaller than the pulley of the first machine, the second machine will then operate as an induction generator, and will return to the line as much power as the first motor draws from the line, less the losses of the second machine. By properly selecting the ratio of pulleys, the first machine can be caused to draw full load current and full load energy from the line. In this way, the total energy consumed is equivalent to the total of the losses of both machines, which is approximately twice the losses of a single machine. The figure shows the connection of the wattmeters, without necessary switches, for reading the total energy by two wattmeter method. Detailed connection of the wattmeter is shown in fig. 2,883. It is usual, in making temperature tests, to insert one or more thermometers in what is supposed to be the hottest part of the winding, one on the surface of the laminae and one in the air duct between the iron laminae. The test should be continued until the difference in temperature between any part of the motor and the air reaches a steady value. The motor should then be stopped and the temperature of the armature also measured. For the method of testing wound armature type induction motors of very large size, see fig. 2,890. For the approved way of taking temperature readings and interpreting results, see the "Standardization Rules of the A. I. E. E.".

readings and the other for high voltage readings; on these scales the values of the graduations for low voltages are usually marked with red figures, while those for high voltages are marked with black figures. A voltmeter carrying two scales must also contain two resistances in place of one; a terminal from each of these coils must be connected with a separate binding post, but the remaining terminal of each resistance is joined to a wire which connects through the fine wire coil with the third binding post of the meter. The two first mentioned binding posts are usually mounted at the left hand side of the meter and the last mentioned binding post and key at the right hand side.

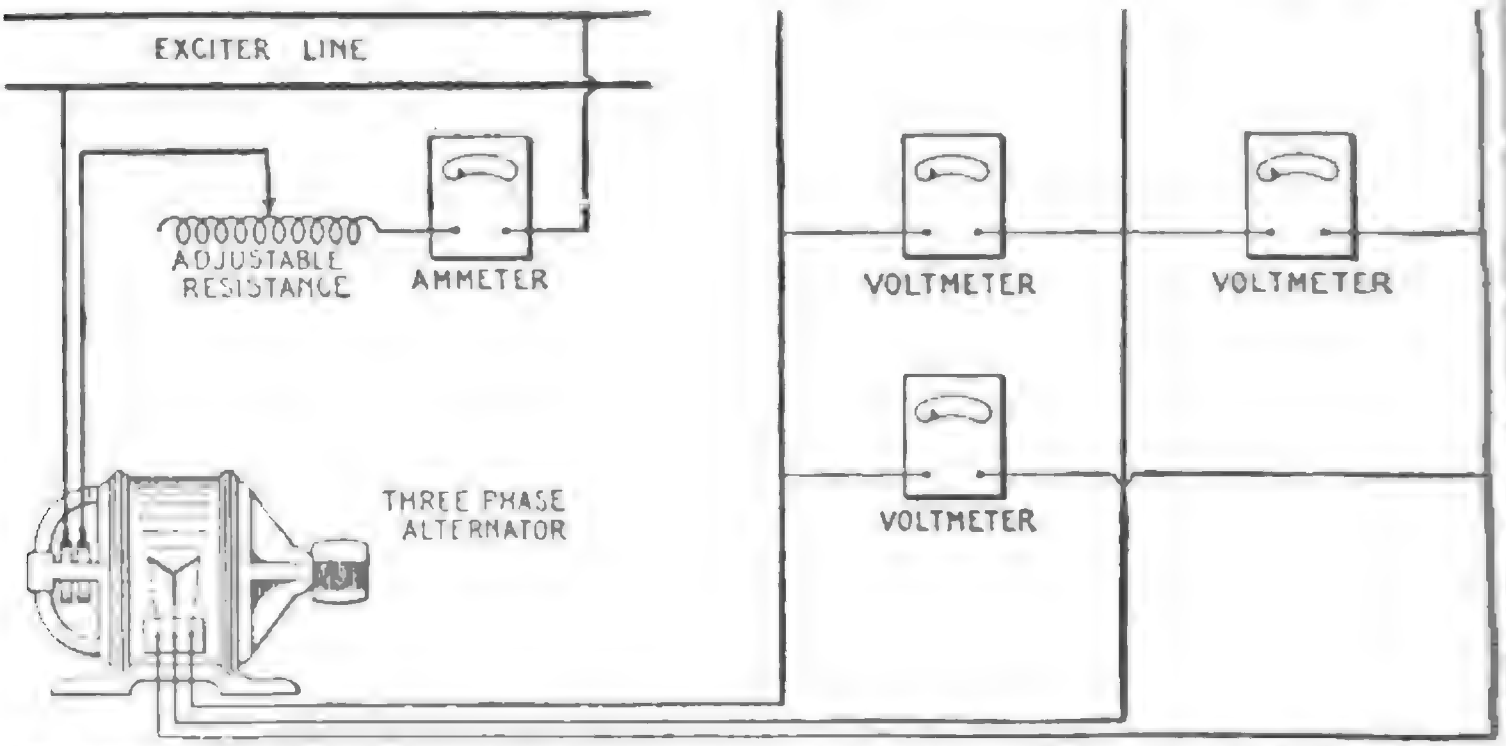


FIG. 2,887.—Alternator excitation or magnetization curve test. The object of this test is to determine the change of the armature voltage due to the variation of the field current when the external circuit is kept open. As here shown, the field circuit is connected with an ammeter and an adjustable resistance in series with a direct current source of supply. The adjustable resistance is varied, and readings of the voltmeter across the armature, and of the ammeter, are recorded. The speed of the generator must be kept constant, preferably at the speed which is given on the name plate. The excitation or magnetization curve of the machine is obtained by plotting the current and the voltage.

The resistance corresponding to the high reading scale is composed of copper wire having the same diameter as that constituting the resistance for the low reading scale, but as the capacity of the former scale is generally a whole number of times greater than that of the latter scale, the resistances for the two must bear the same proportion.

Ques. How is a two scale voltmeter connected?

Ans. In the connection of a two scale voltmeter in circuit, the single binding post is always employed regardless of which scale is desired. If, then, the voltage be such that it may be measured on the low reading scale, the other binding post employed is that connected to the lower of the two resistances

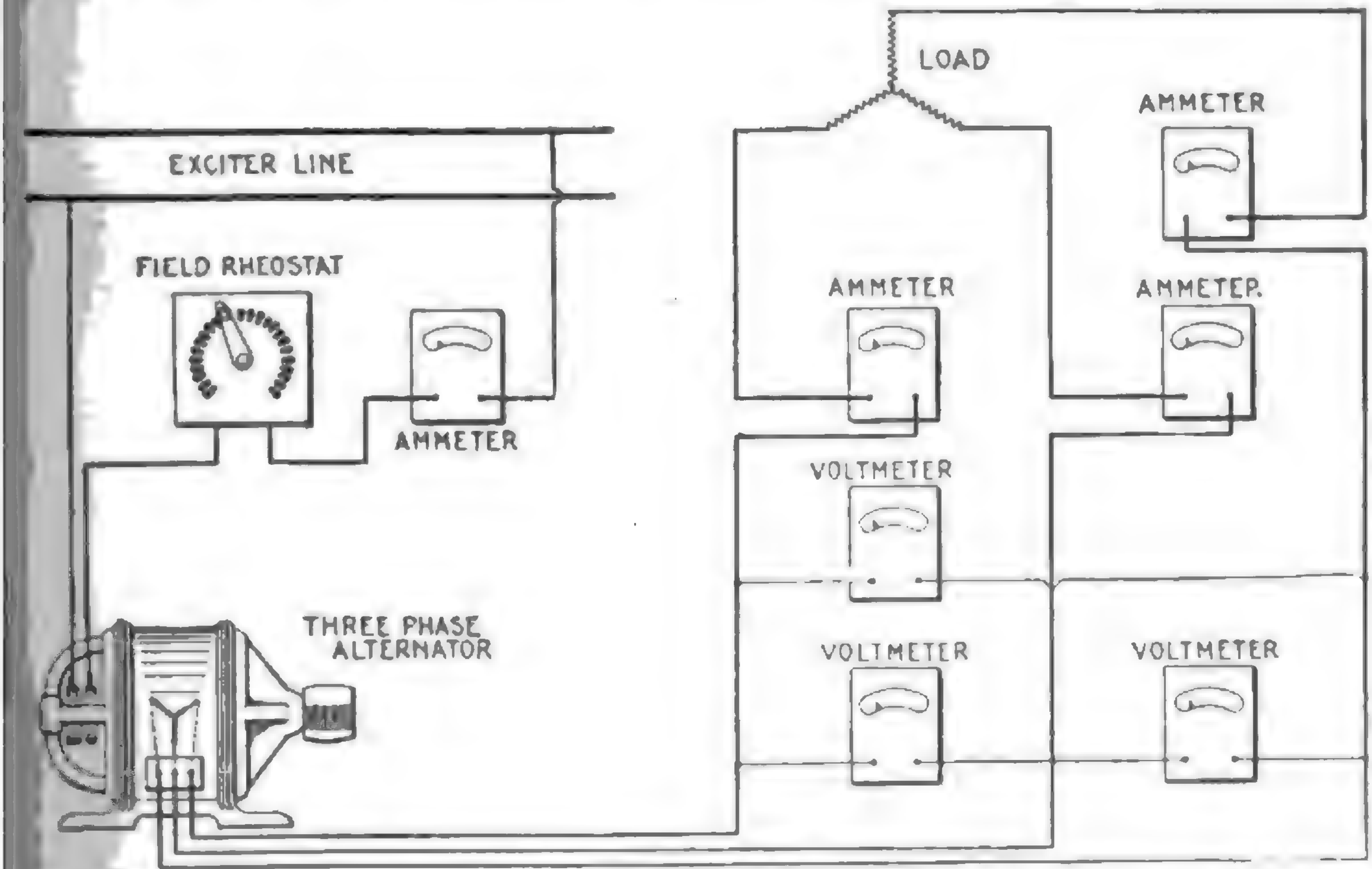


FIG. 2,888.—Three phase alternator synchronous impedance test. In determining the regulation of an alternator, it is necessary to obtain what is called the *synchronous impedance* of the machine. To obtain this, the field is connected, as shown above. Voltmeters are removed and the armature short circuited with the ammeters in circuit. The field current is then varied, the armature driven at synchronous speed, and the armature current measured by the ammeters in circuit. The relation between field and armature amperes are then plotted. The combination of the results of this test, with those obtained from the test shown in fig. 2,887, are used in the determination of the regulation of an alternator. Engineers differ widely in the application of the above to the determination of regulation, and employ many empirical formulae and constants for different lines of design.

NOTE.—Three phase alternator load test. By means of the connection shown in fig. 2,888, readings of armature current and field amperes can be obtained with any desired load. The field current can be varied also so as to maintain constant armature voltage irrespective of load; or the field current may be kept constant and the armature voltage allowed to vary as the load increases. The connections may also be used to make a temperature test on the alternator by loading it with an artificial load. In some cases after the alternator is installed the connection may be used to make a temperature test, using the actual commercial load the alternator is furnishing.

contained within; if, however, the pressure be higher than those recorded on the low reading scale, the binding post connected to the higher of the two resistances contained within is used.

Inasmuch as the capacities of the scales are usually marked on or near the corresponding binding posts, there will generally be no difficulty in selecting the proper one of the two left hand binding posts.

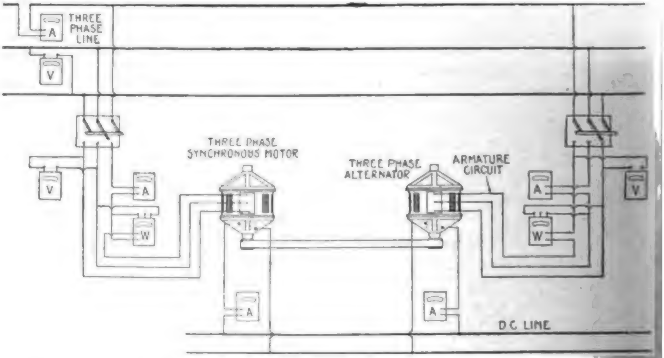
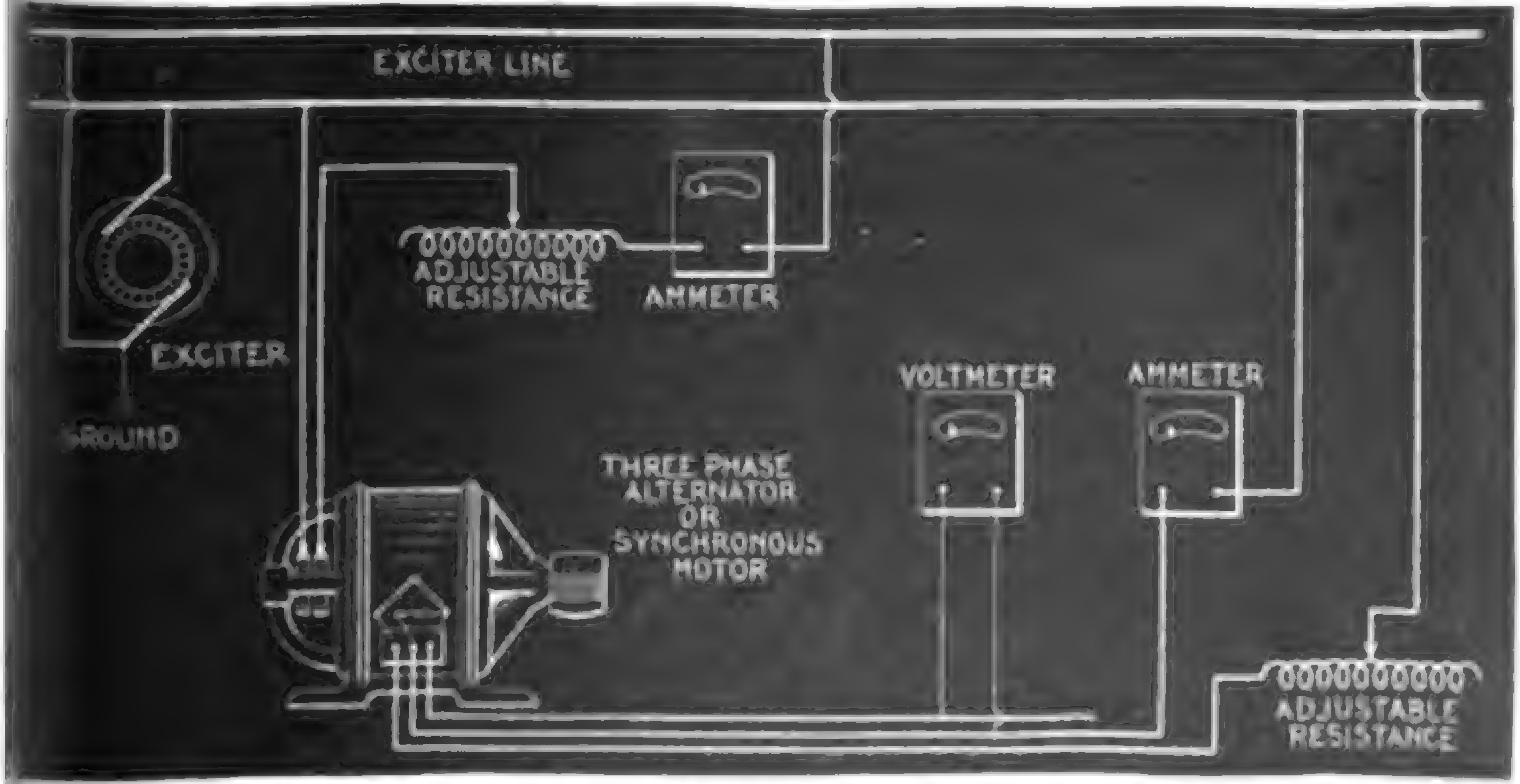


FIG. 2,889.—Three phase alternator or synchronous motor temperature test. In this test two alternators or synchronous motors of same size and type are used, and are belted together, one to be driven as a synchronous motor and the other as an alternator. The method employed is to synchronize the synchronous motor with the alternator or alternators on the three phase circuit, and then connect to the line by means of a three pole single throw switch. The alternator is then similarly synchronized with the alternator of the three phase circuit and thrown onto the line. By varying the field of the alternator it can be made to carry approximately full load, and the motor will then be also approximately fully loaded. The usual method is to have the motor carry slightly in excess of full load, and the alternator slightly less than full load. Under these conditions the motor will run a little warmer than it should with normal load, while the alternator will run slightly cooler. Temperature measurements are made in the same way as discussed under three phase motors. The necessary ammeters, voltmeters and wattmeters for adjusting the loads on the motors and generator are shown in above figure. If pulleys be of sufficient size to transmit the full load, with, say one per cent. slip, the pulley on the motor should be one per cent. larger in diameter than the pulley on the alternator, so as to enable the alternator to remain in synchronism and at the same time deliver power to the circuit. With very large machines under test, it is inadvisable to use the above method as it is sometimes difficult to so adjust the pulleys and belt tension that the belt slip will be just right to make up for the difference in diameter of the pulleys, and very violent flapping of the belt results. To meet such cases, various other methods have been devised. One which gives consistent results is shown in fig. 2,890.

Ques. How is a two scale voltmeter connected when the binding posts are not marked?

Ans. If only an approximate idea is possessed of the voltage to be measured, it is always advisable to connect to the binding post corresponding to the high reading scale of the meter in order to determine if the measurement may not be made safely and more accurately on the low reading scale. In any case, some knowledge must be had of the voltage at hand, else the high reading portion of the instrument may be endangered.



c. 2,890.—Three phase alternator or synchronous motor temperature test. Supply the field with normal field current. The armature is connected in open delta as illustrated, and full load current sent through it from an external source of direct current, care being taken to ground one terminal of the dynamo so as to avoid danger of shock due to the voltage on the armature winding. The field is then driven at synchronous speed. If the armature be designed to be connected star for 2,300 volts, the voltage generated in each leg of the delta will be 1,330 volts, and unless one leg of the dynamo were grounded, the tester might receive a severe shock by coming in contact with the direct current circuit. The insulation of the dynamo would also be subjected to abnormal strain unless one terminal were grounded. By the above method the field is subjected to its full copper loss and the armature to full copper loss and core loss. Temperature readings are taken as per standardization rules of the A. I. E. E. This method may also be used with satisfactory results on large three phase motors of the wound rotor type. If the alternator pressure be above 600 volts, a pressure transformer should be used in connection with the voltmeter.

Too much care cannot be taken to observe these precautions whenever the voltmeter is used, for the burning out or charring of the insulation either in the fine wire coil or in the high resistance of the meter by a excessive current, is one of the most serious accidents that can befall the instrument.

If a voltmeter has been subjected to a voltage higher than that for which it was designed, yet not sufficiently high to injure the insulation, but high enough to cause the pointer to pass rapidly over the entire scale, damage has been done in another way. The pointer being forced against the side of the case in this manner, bends it more or less and so introduces an error in the readings that are afterward taken.

The same damage will be done if the meter be connected in circuit so that the current does not pass through it in the proper direction, although in this case the pointer is not liable to be bent so much as when it is forced to the opposite side of the meter by an abnormal current, since then it has gained considerable momentum which causes a severer impact. The extent of the damage may be ascertained by noting how far away from the zero mark the pointer lies when no current is passing through the instrument. If this distance be more than two-tenths of a division, the metal case enclosing the working part should be removed and the pointer straightened by the ul use of a pair of pinchers.

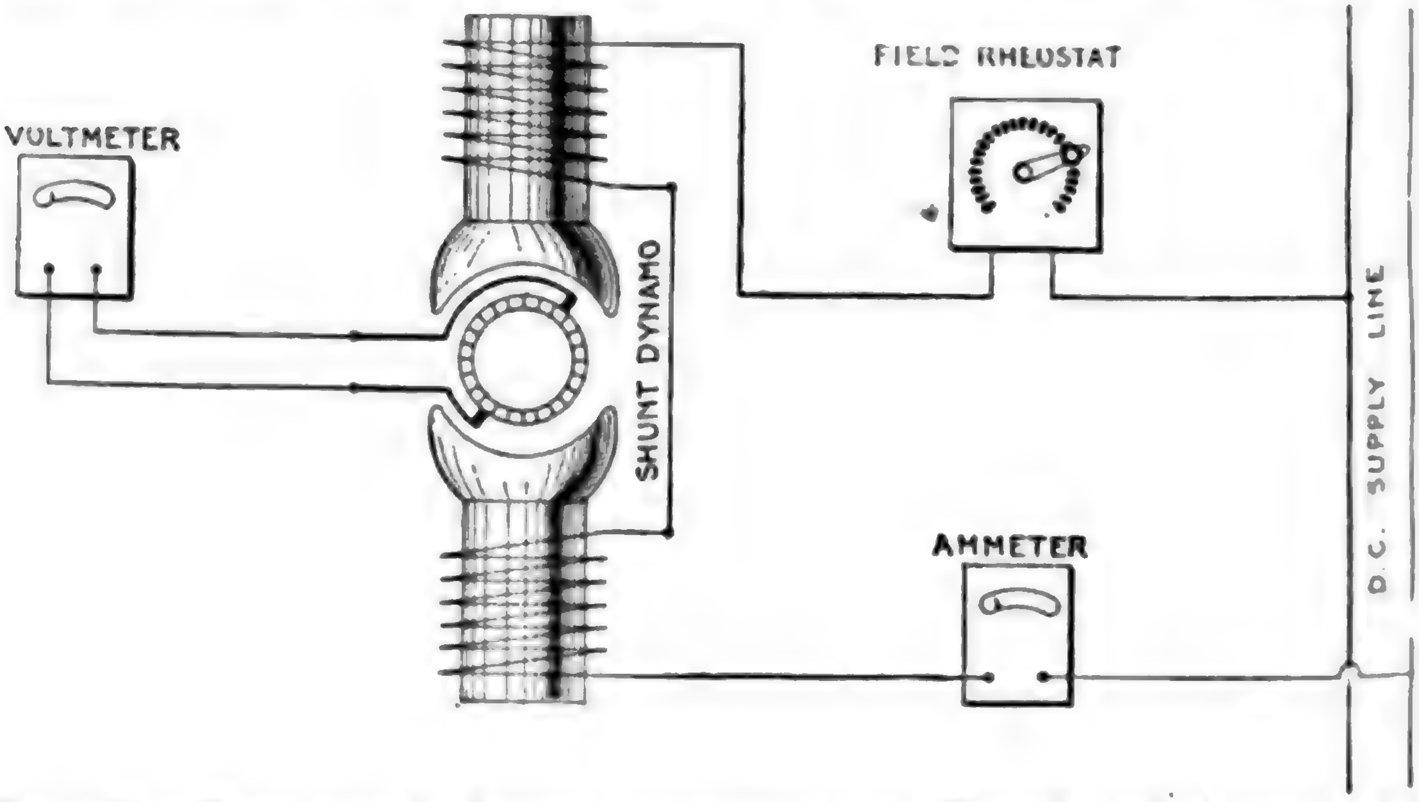


FIG. 2,891.—Direct motor or dynamo magnetization test. The object of this test is to determine the variation of armature voltage without load, with the current flowing through the field circuit. The armature should be driven at normal speed. The adjustment resistance in the field circuit is varied and the voltage across the armature measured. The curve obtained by plotting these two figures is usually called magnetization curve of the dynamo. It is usual to start with the higher resistance in the field circuit so that very small current flows, gradually increasing this current by cutting out the field resistance. When the highest no load voltage required is reached, the field current is then diminished, and what is called the descending (as opposed to the ascending) magnetization curves are obtained. The difference in the two curves is due to the lag of the magnetization behind the magnetizing current, and is caused by the hysteresis of the iron of the armature core.

Ques. What should be noted with respect to location of instruments?

Ans. If they be placed near conductors carrying large currents, the magnetic field developed thereby will produce a change in the magnetism of the instruments and so introduce an error in the readings.

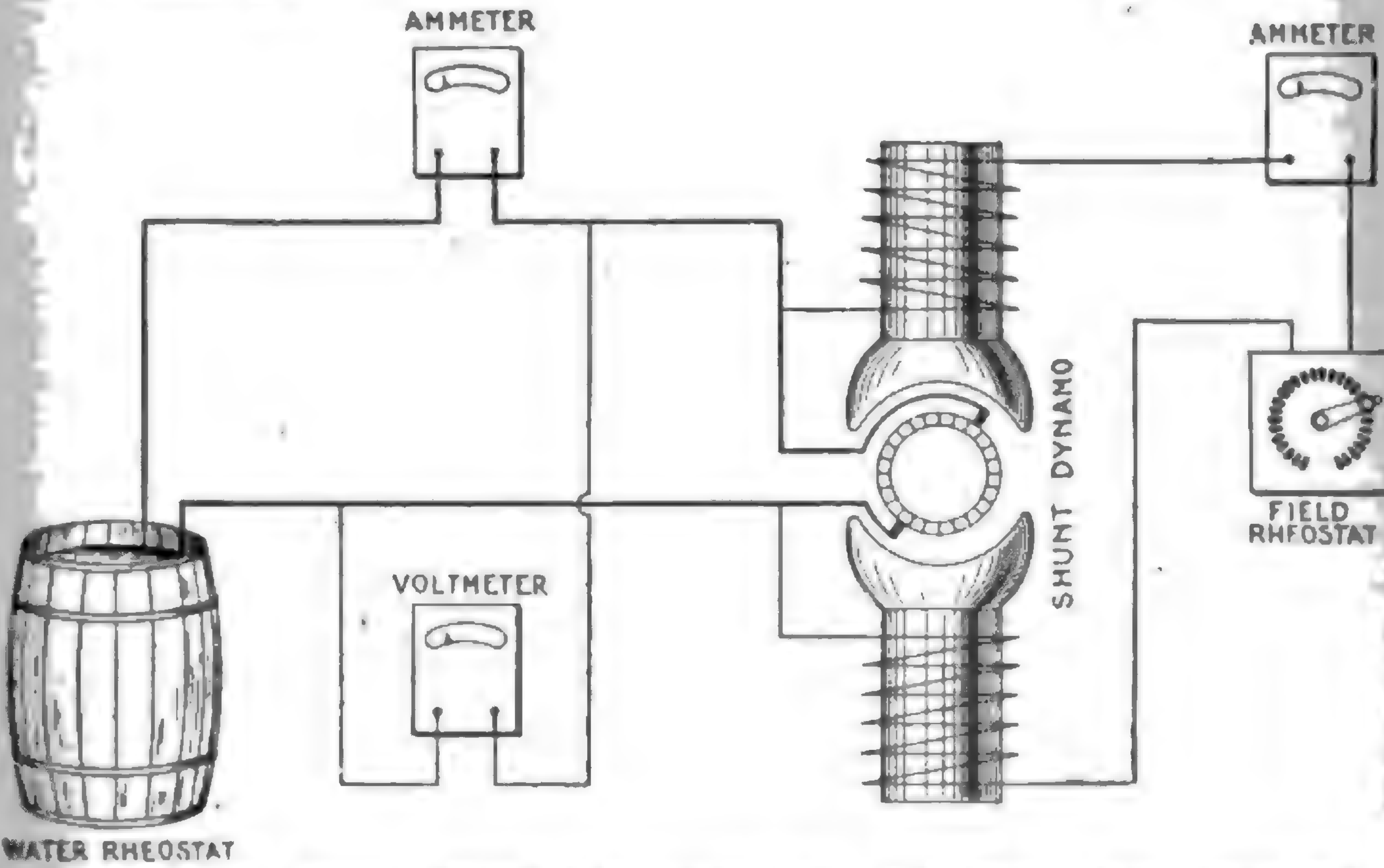


FIG. 2,892.—Shunt dynamo, external characteristic test. The external characteristic of a shunt dynamo is a curve showing the relation between the current and voltage of the external circuit. This is obtained by the connection as here shown. The shunt field is so adjusted that the machine gives normal voltage when the external circuit is open. The field current is then maintained constant and the external current varied by varying the resistance in the circuit. By plotting voltage along the vertical, against the corresponding amperes represented along the horizontal, the external characteristic is obtained.

Ques. How should portable instruments be wired?

Ans. The wires must be firmly secured to the supports on which they rest, so as to reduce the possibility of their being pulled by accident, and so causing the instruments to fall.

A fall or a rough handling of the meter at once shows its effect on the readings, for as much harm is done as would result from a similar treatment of a watch.

The hardened steel pivots used in all high grade voltmeters are ground and polished with extreme care so as to secure and maintain a high degree of sensitiveness. The jewels on which the moving parts revolve are of sapphire, and they too must necessarily be made with skill and carefulness; if, therefore, the jewels become cracked and the pivots dulled by careless handling, the meter at once becomes useless as a measuring instrument.

Ques. How should readings be taken?

Ans. The deflections of the pointer should be read to tenths of a division; this can be done with considerable accuracy, especially after a little practice.

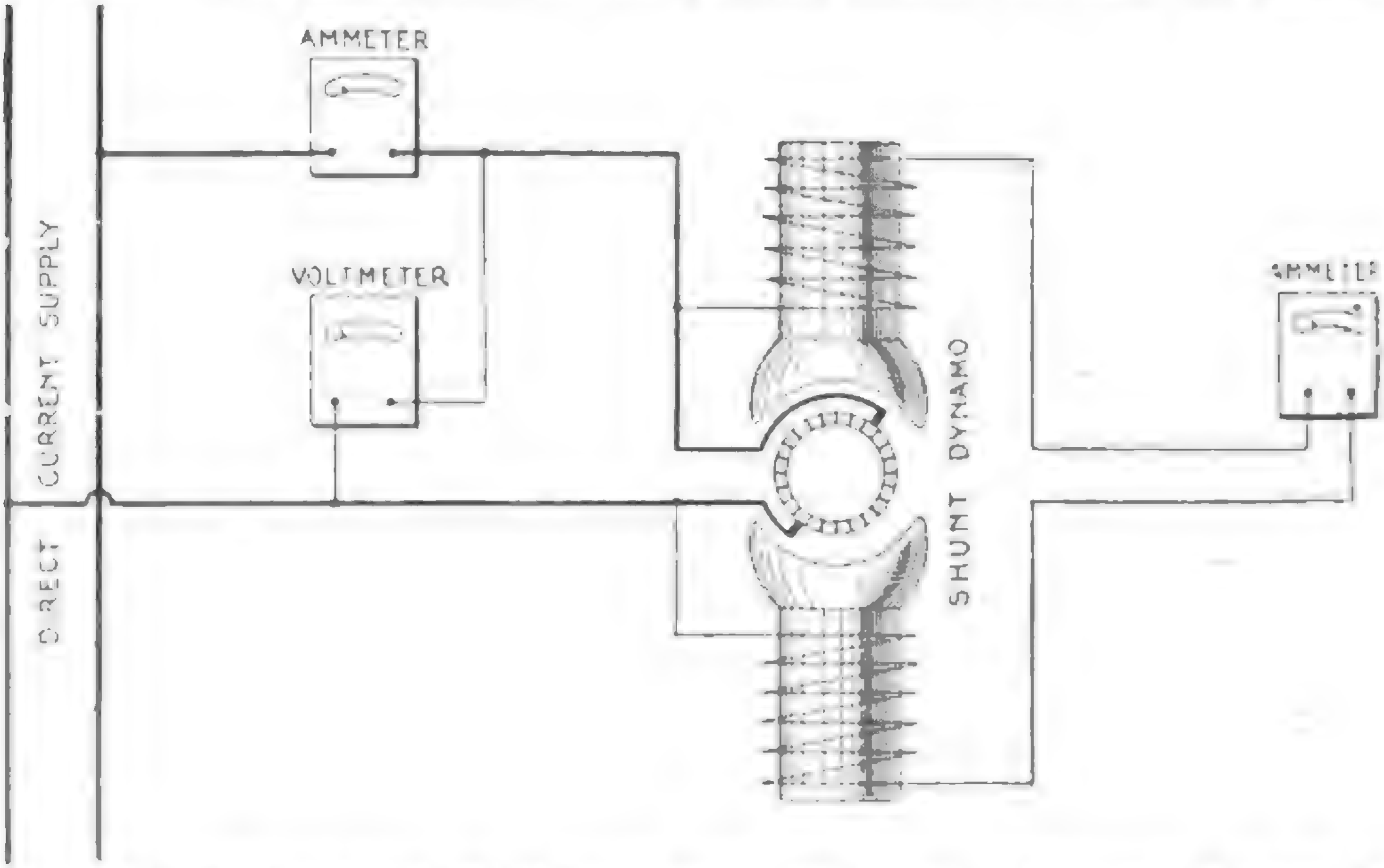


Fig. 2,893.—Load and speed test of direct current shunt motor. The object of this test is to maintain the voltage applied to the motor constant, and to vary the load by means of a brake and find the corresponding variation in speed of the machine and the current drawn from the circuit. If the motor be a constant speed motor, the field resistance is maintained constant. The above indicates the method of connecting instruments for the test alone; for starting the machine the ordinary starting box, should, of course, be inserted.

For very accurate results, a temperature correction should be applied to compensate the effect which the temperature of the atmosphere has upon the resistance of the meter when measurements are being taken. In ordinary station practice the temperature correction is negligible, being for resistance corresponding to the high scale in first class meters, less than one-quarter of 1 per cent. for a range of 35 degrees above or 35 degrees below 70 degrees Fahrenheit.

Ques. What attachment is sometimes provided on station voltmeters used for constant pressure service?

Ans. A normal index.

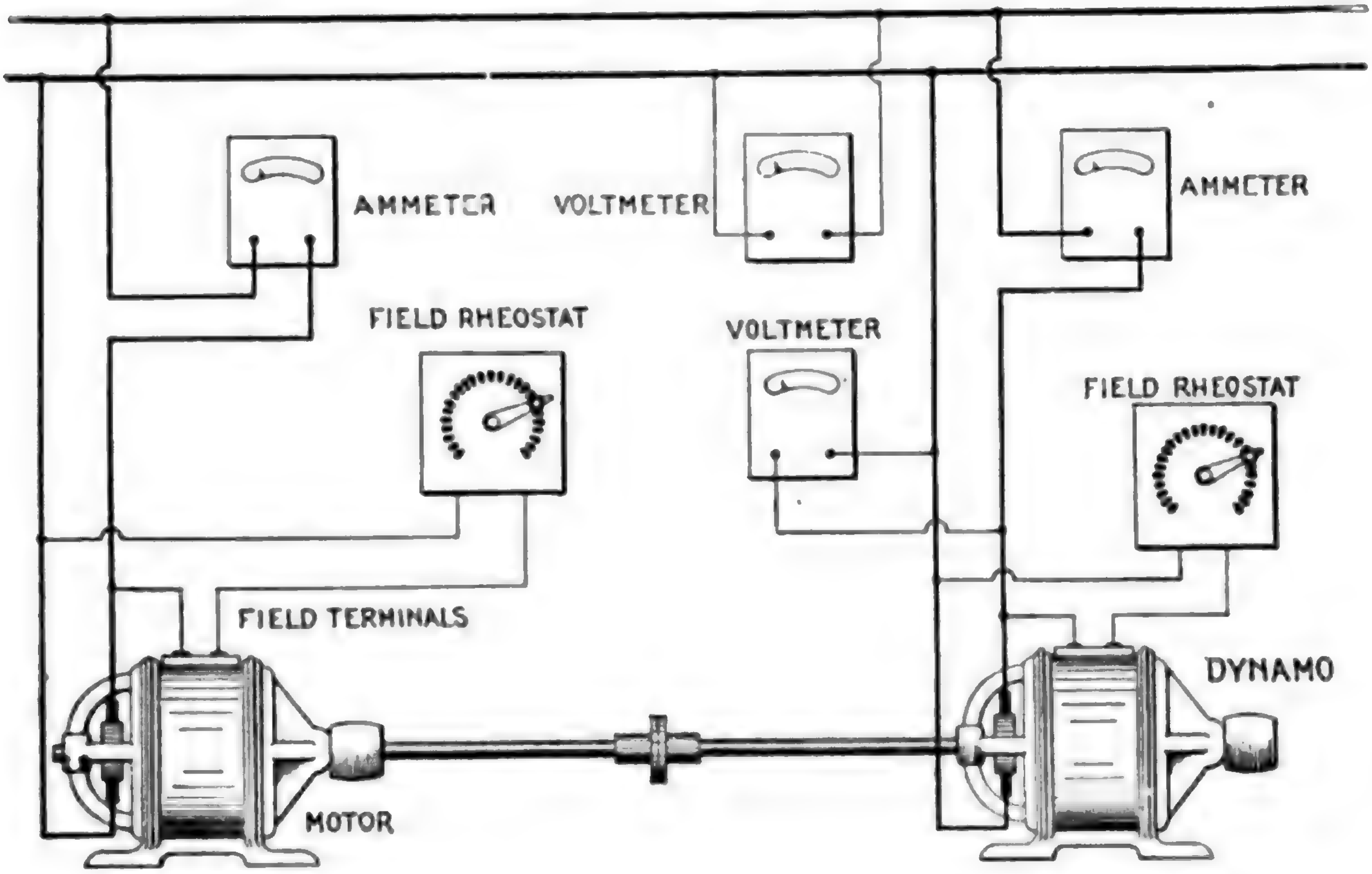


FIG. 2,894.—Temperature test of direct current motor or dynamo; loading back method In making temperature tests on a small dynamo it is usual to drive the dynamo with a motor and load the dynamo by means of a lamp bank or resistance, the voltage across the dynamo being maintained constant, and the current through the external circuit adjusted to full load value. The temperatures are then recorded, and when they reach a constant value above the temperature of the atmosphere, the test is discontinued. Similarly, in making a test on a small motor, the motor is loaded with a dynamo and the load increased until the input current reaches the normal full load value of the motor, the test being conducted as for a small dynamo. When, however, the apparatus, either motor or dynamo, reaches a certain size, it becomes necessary, in order to economize energy, to use what is called the **loading back method**, as here illustrated. The motor is started in the usual way, with the dynamo belted to it, the circuit of the dynamo being open. The field of the dynamo is then adjusted so that the dynamo voltage is equal to that of the line. The dynamo is then connected to the circuit and its field resistance varied until it carries normal full load current. Under these conditions, if the motor and dynamo be of the same size and type, the motor will carry slightly in excess of full load, the difference being approximately twice the losses of the machines. Under these conditions the total power drawn from the line is equal to twice the loss of either machine. Temperature readings are taken as in other temperature tests.

Ques. What precaution must be taken in connecting station voltmeters?

Ans. Care must be taken to guard against any short circuiting of the voltmeter, which, would mean a short circuiting of the generator, and as a result the probable burning out of its armature.

The high resistance of the voltmeter prevents any such occurrence when it is connected in the proper way, but should one side of the circuit be grounded to the metal case or frame of the meter, a careless handling of the lead connected with the other side of the circuit would produce the result just mentioned.

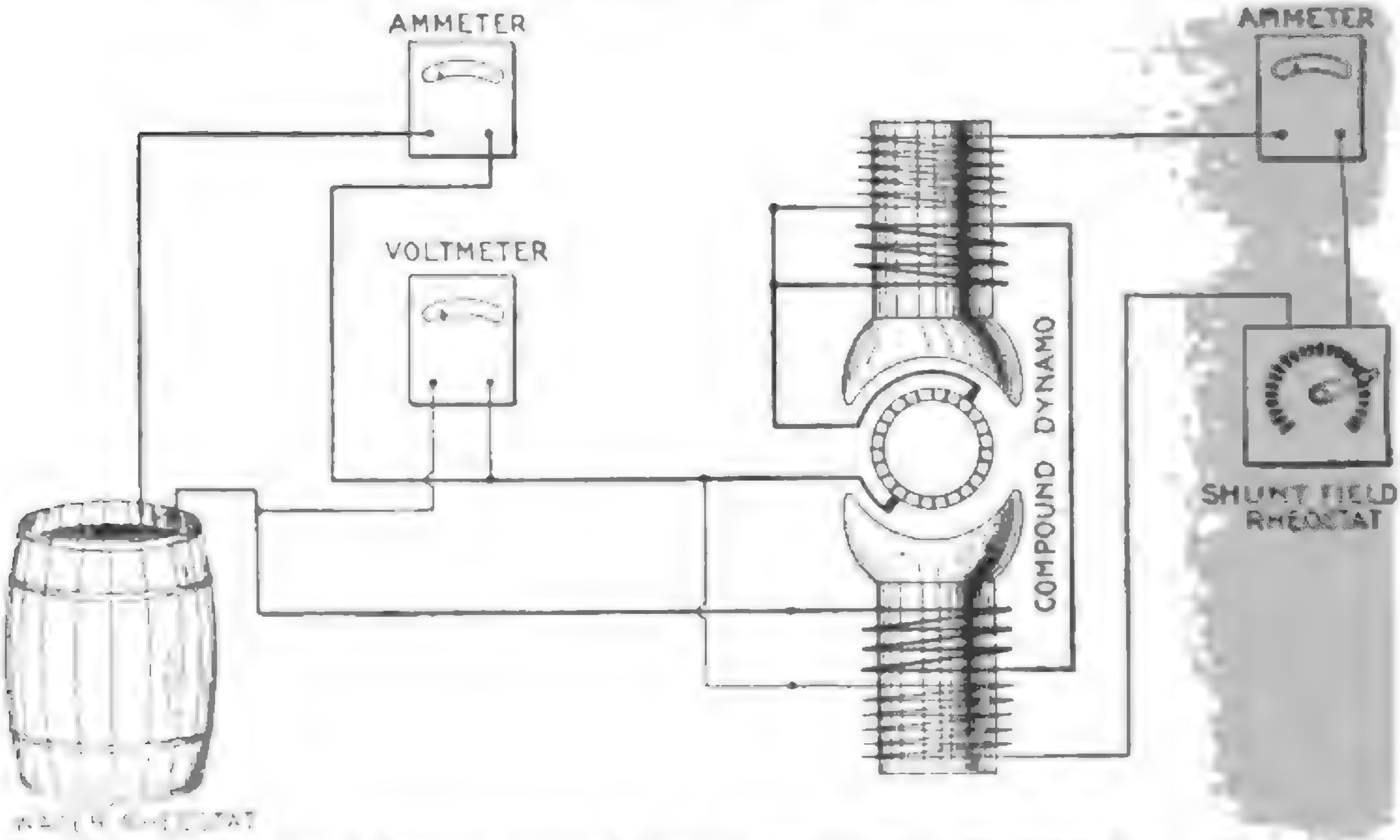
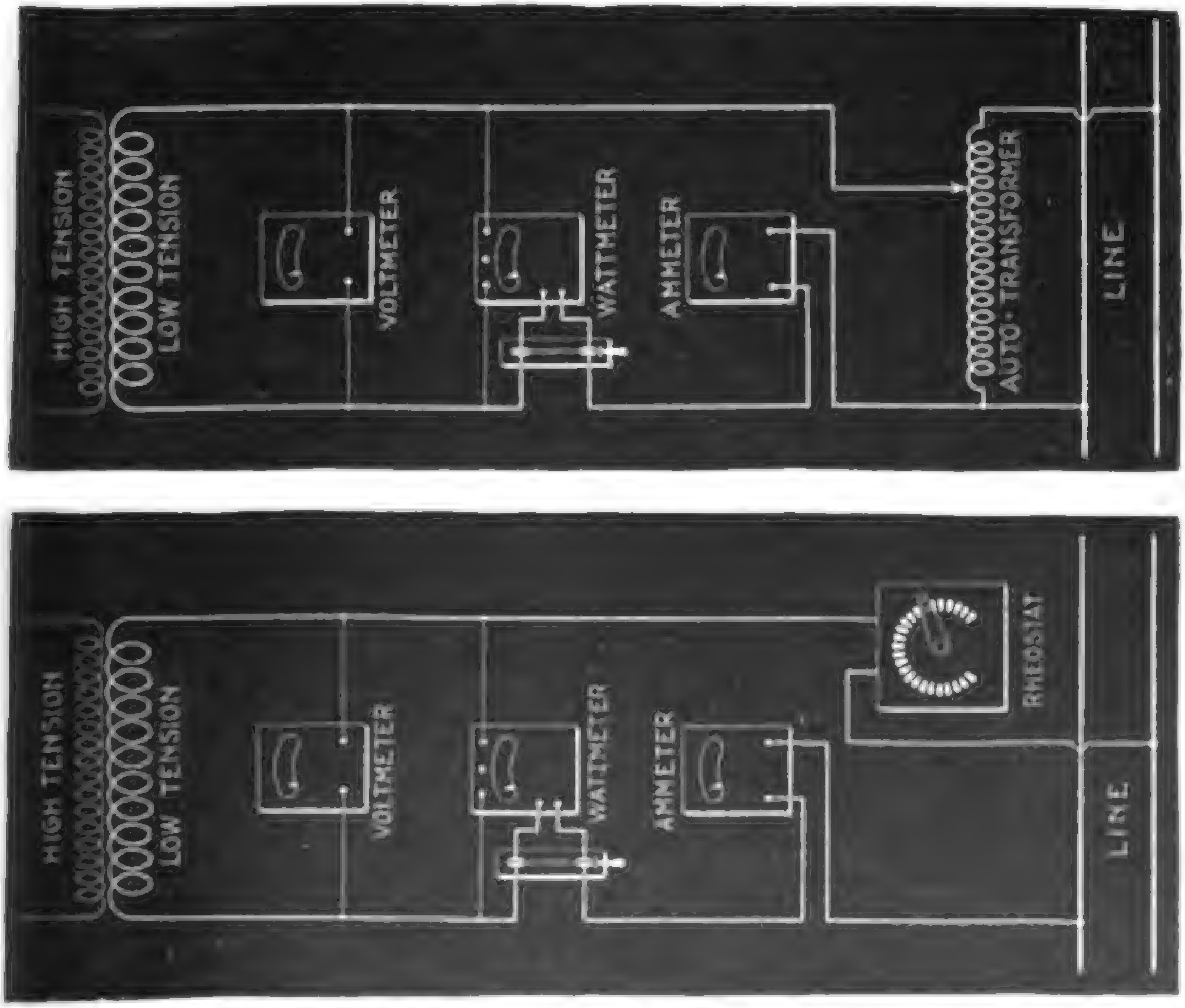


FIG. 2,895.—Compound dynamo external characteristics test; adjustable load. The object of this test is to determine the relation between armature voltage and armature current. Shunt field is adjusted to give normal secondary voltage when the external circuit is open. The load is then applied by means of an adjustable resistance or lamp bank, and readings of external voltage and current recorded. If the machine be normally compounded, the external voltage will remain practically constant throughout the load range. If the machine be under-compounded, the external voltage will drop with load, while if over-compounded, there will be a rise in voltage with increase in load.

Ques. Why do station voltmeters indicate a voltage slightly lower than actually exists across the leads?

Ans. Since they are usually connected permanently in circuit; a certain amount of heat is developed in the wiring of the instrument.



FIGS. 2,896 and 2,897.—Transformer core loss and leakage, or exciting current test. With the primary circuit open, the ammeter indicates the exciting or no load current. It should be noted that all instruments are inserted on the low voltage side, for both safety of the operator and because the measurements are more accurate. The no load primary current, if the ratio of transformation be 10 : 1, will be one-tenth of the measured secondary current. The wattmeter connected, as shown, measures the sum of the losses, in the transformer, in the pressure coil of the wattmeter, and in the voltmeter. On all standard makes of portable instruments, the resistance of the wattmeter pressure coil and of the voltmeter is given, and the loss in either instrument is the square of the voltage at its terminals, divided by its resistance. Subtracting these losses from the total indicated upon the wattmeter, gives the true core or iron loss. It should be noted that in this diagram is shown an auxiliary transformer with a number of taps for obtaining the exact rated voltage of the transformer under test. In fig. 2,897 is shown, in general, the same connections as in fig. 2,896, except that the auto-transformer has been replaced by a resistance. If the line voltage available be not much in excess of the rated voltage of the transformer under test, very little error is introduced by the use of the resistance method. However, if the difference be 10 per cent. or more the auxiliary transformer shown in fig. 2,896 should be used. Measurements made under the resistance method always give lower results than those obtained with the auxiliary transformer.

The effect of this heat increases the voltmeter resistance and consequently reduces the current below that which otherwise would pass through the meter; since the deflections of the pointer are governed by the strength of the current, station voltmeters invariably indicate a voltage slightly lower than that which actually exists across their leads.

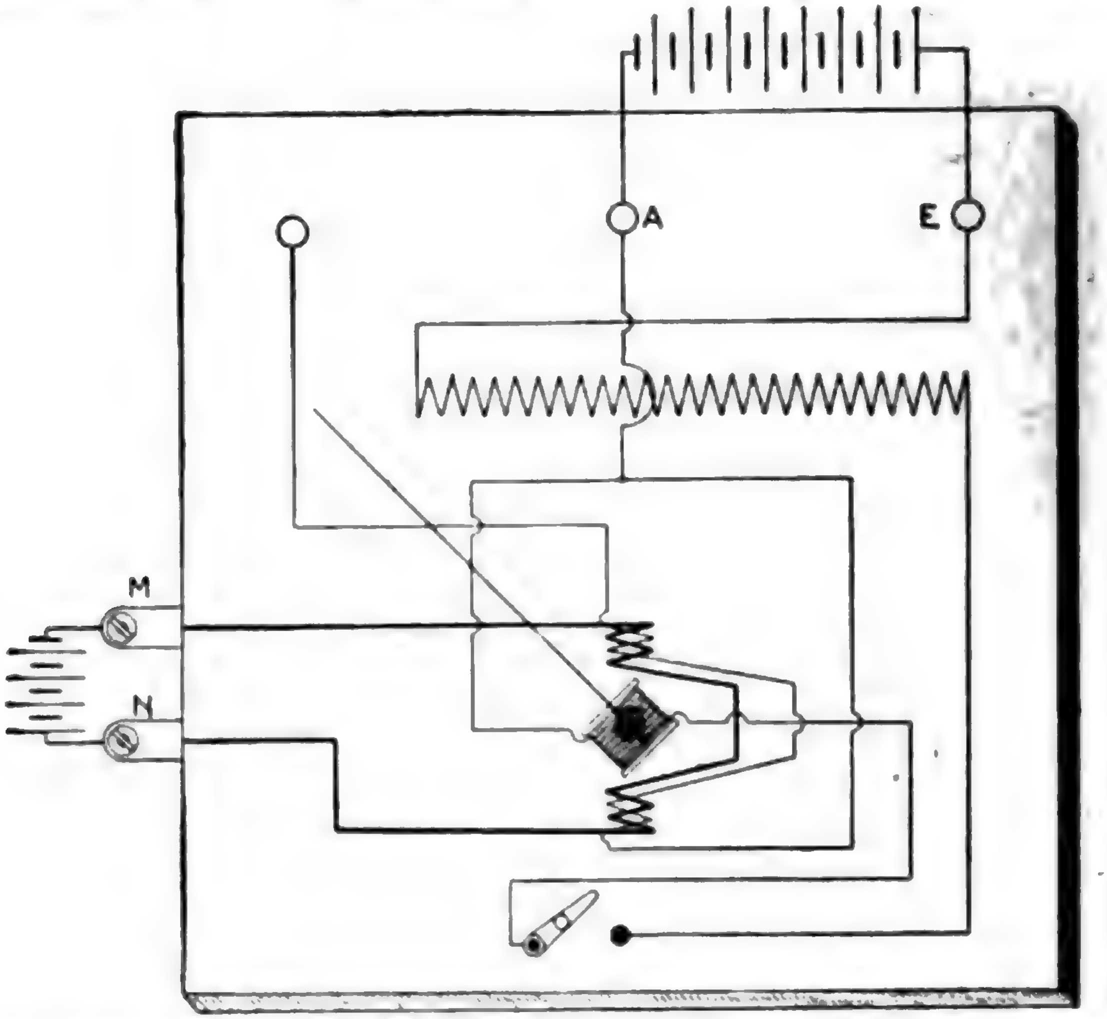


FIG. 2,898.—Diagram of connections for calibrating a wattmeter. The calibration of a portab wattmeter is accomplished with direct current of constant value which is passed through the series winding by connecting the source thereof with the current terminals. A direct current voltage which may be varied throughout the range of the wattmeter is also applied to the instrument between the middle and right hand pressure terminals A and E the wiring in the meter between these terminals being such that its differential winding is then cut out of circuit. The method of procedure consists in comparing the deflections on the wattmeter at five or six approximately equidistant points over its scale with the corresponding products of volts and amperes used to obtain them. The changes in the wattmeter deflections are effected by merely varying the voltage, the value of the current being maintained constant at a value which represents the full current capacity of the meter.

NOTE.—**Checking up of a recording wattmeter.** This may conveniently be done by noting the deflections at short intervals on an ammeter connected in circuit, and also the readings on the dial of the recording wattmeter during this period. If this test be continued for an appreciable time, the product of the pressure in volts, the current in amperes, and the time in hours, should equal the number of watthours recorded on the counters of the dial.

NOTE.—**Transformer testing.** In the early days of transformer building, before the commercial wattmeter had been perfected, leakage or exciting current was the criterion of good design. After the introduction of the wattmeter, core loss became the all important factor, and for a long time the question of leakage current was lost sight of. With the introduction of silicon steel, leakage or exciting current again assumed prominence. Keeping in mind the fact that all characteristics of a transformer are of more or less importance, it is essential that the user of such apparatus have at hand the necessary facilities for making tests of all such variable quantities. The tests which all users of transformers should make, are ren in this chapter.

Ques. Can direct current be measured by an alternating current voltmeter?

Ans. Yes.

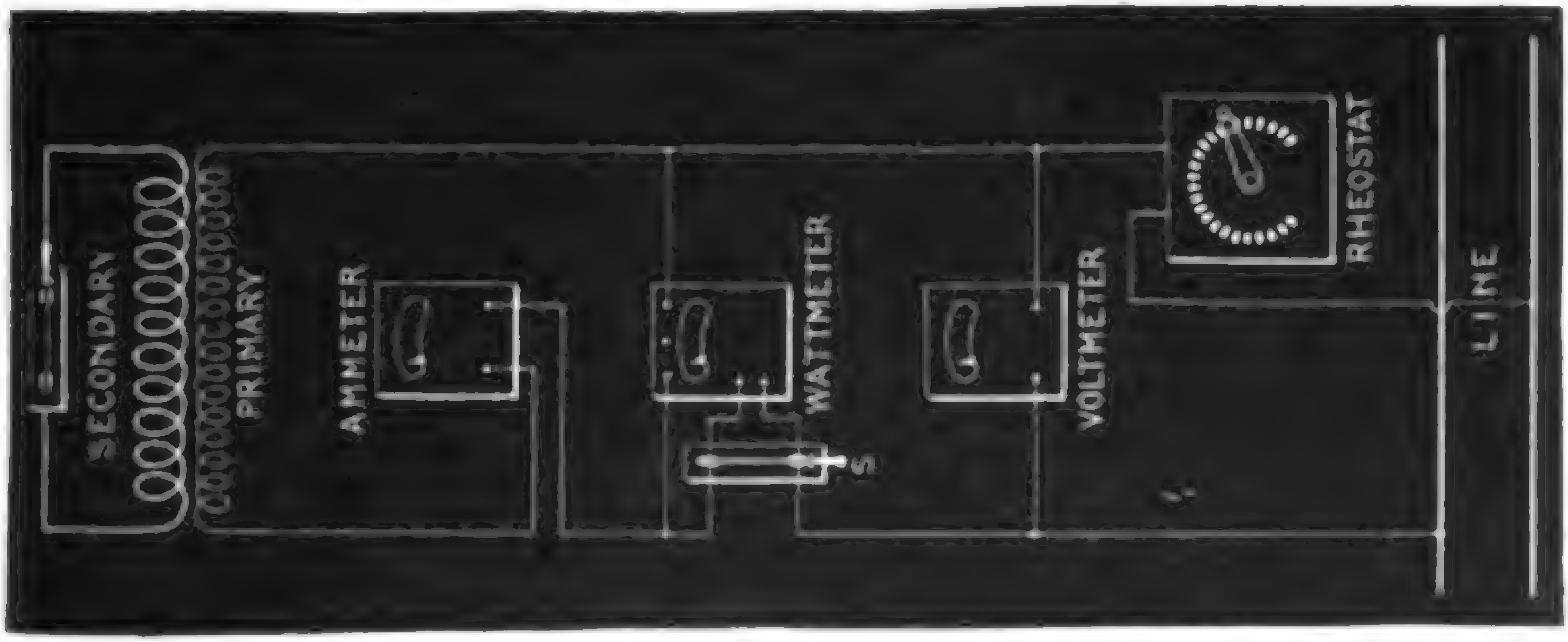


FIG. 2,899.—Transformer copper loss by wattmeter measurement and impedance. At first glance, this method would seem better than the calculation of loss after measurement of the resistance. However, it should be noted that the wattmeter is, in itself, subject to considerable error under the low power factor that will exist in this test. The secondary of the transformer is short circuited, and a voltage applied to the primary which is just sufficient to cause full load primary current. If full current pass through the primary of the transformer with the secondary short circuited, the secondary will also carry full load current. With connections as shown, and with the full load current, the voltmeter indicates the impedance volts of the transformer. This divided by the rated voltage gives what is called the *per cent. impedance of the transformer*. In a commercial transformer of 5 kw., this should be approximately 3 per cent. The iron loss of the transformer under approximately 3 per cent. of the normal voltage will be negligible, and the losses measured will be the sum of the primary and secondary copper losses. As in the discussion of the core loss measurements, the wattmeter readings must be corrected for the loss in its pressure coil, the method of correction being the same as that discussed under the core loss measurement. If the impedance volts, as measured, be divided by the primary current, the impedance of the transformer is obtained. The reciprocal of this quantity is known by the term "admittance." *When two or more transformers are connected in parallel they divide the load in proportion to their admittance.* It is, therefore, important that the users of transformers know the impedance of the apparatus used, in order to determine whether two or more transformers will operate satisfactorily in parallel. For discussion of wattmeter error on low power factor, see note on page 2,075. For accurate measurement of impedance, the voltmeter should be connected directly across the terminals of the transformer rather than as shown in the diagram.

NOTE.—**Transformer copper loss test.** The usual and best method of obtaining copper losses is to separately measure the primary and secondary resistance and calculate from these the primary and secondary copper losses. For general diagram of connections and discussion of the drop method, see fig. 2,875. The current should be kept well within the load current of the transformer to avoid temperature rise during the test. In other words, the resistance of the coil is the voltage across its terminals divided by the current. The resistance of the primary coil can be measured similarly. The copper loss in watts in each coil will then be the product of the resistance and the square of the rated current for that coil. The total copper loss will be the sum.

Ques. What would be the effect of placing a direct current voltmeter across an alternating current circuit, and why?

Ans. There would be no deflection of the pointer owing to the rapid reversals of the alternating current.

Ques. What are the usual capacities of alternating current voltmeters?

Ans. They are 3, 7.5, 10, 12, 15, 20, 60, 75, 120, 150, 300 and 600 volts, but these capacities may each be increased by the use of a multiplier.

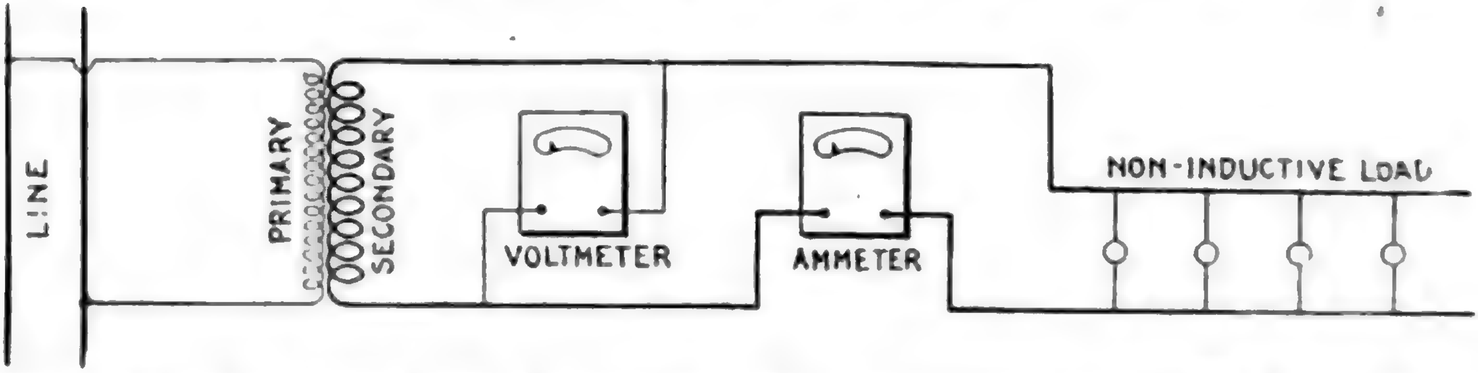


FIG. 2,900.—Temperature test of transformer with non-inductive load. The figure shows the simplest way of making the test. Connect the primary of the transformer to the line as shown, and carry normal secondary load by means of a bank of lamps or other suitable resistance, until full load secondary current is shown by the ammeter in the secondary circuit. The transformer should then be allowed to run at its rated load for the desired interval of time, temperature readings being made of the oil in its hottest part, and also of the surrounding air. Where temperatures of the coil rather than temperatures of the oil are desired, it is necessary to use the resistance method. This is obtained by first carefully measuring the resistance of both primary and secondary coils at the temperature of the room, and then, after the transformer has been under heat test for the desired time, disconnect it from the circuit and again measure the resistance of primary and secondary. For proper method of calculating the temperature rise from resistance measurements, the reader is referred to the standardization rules of the A. I. E. E. In making resistance measurements of large transformers by the drop method care should be taken to allow both ammeter and voltmeter indications to settle down to steady values before readings are taken. This may require several minutes. Each time the current is changed it is necessary in order to obtain check values on resistance measurements, to wait until the current is again settled to its permanent value before taking readings. All resistance measurements must be taken with great care, as small errors in the measurement of the resistance may make very large errors in the determination of the temperature rise. The method above described is satisfactory for small transformers. Where large units are to be tested, the cost of current for testing becomes an important item. The "bucking test" as in fig. 2,901, is more economical.

Ques. How are station voltmeters usually attached to the switchboard?

Ans. They are usually bolted to the switchboard by means of four iron supports mounted on the back of the instrument; two of these are fastened near each side of the case.

Under certain conditions, however, as in paralleling of alternators, it is convenient to have the alternating current voltmeter mounted on a swinging bracket at the side of the switchboard. The voltmeter may then be swung around in any desired direction so as to enable the attendant to keep informed of the voltage while switching in each additional alternator.

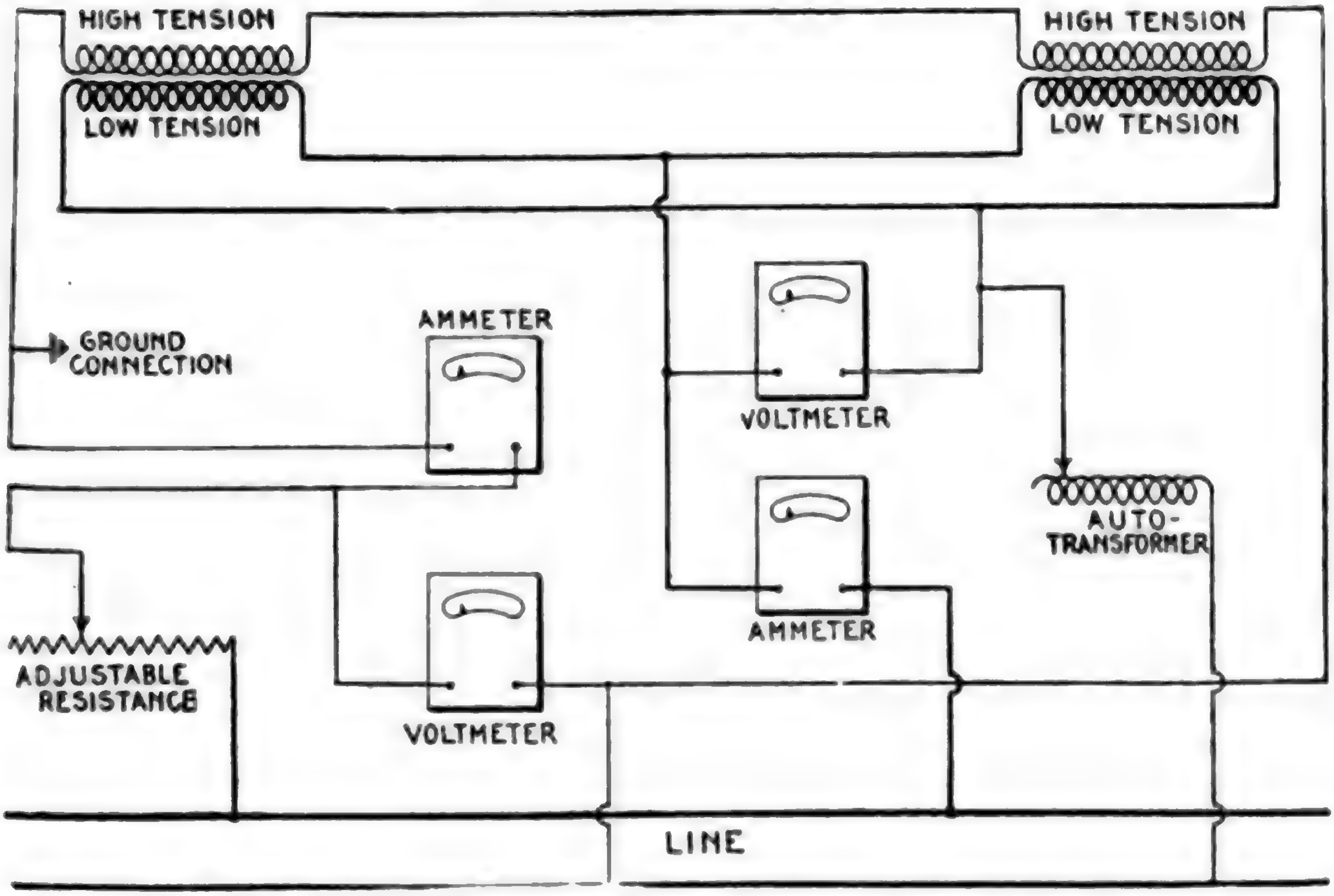


FIG. 2,901.—Transformer temperature "bucking test." For this purpose two transformers of the same size and ratio are required. The connections are as shown. Full secondary voltage is applied, and rheostats or auxiliary auto-transformers are inserted in the circuit to properly regulate the voltage. The primaries are connected with one bucking the other, and a voltage equal to twice the impedance voltage of either transformer inserted in the primary circuit. It should be noted that when the secondaries are subjected to the full secondary voltage, a full primary voltage exists across either primary, but with the primaries connected so that the voltage of one is bucked against the voltage of the other, the resultant voltage in the circuit will be zero. By applying to the primary circuit twice the impedance voltage of either transformer, full primary and secondary current will circulate through both transformers. On the other hand, by subjecting the secondaries to the full secondary voltage, the iron of the transformer will be magnetized as under its regular operating conditions, and the full iron loss of the transformer introduced. This method permits the operation of two transformers under temperature test with their full losses, without taking energy from the line equal to the rated capacity. Measurements of temperature are taken in exactly the same way as above. This method is successfully employed for making temperature tests on transformers of all sizes

Ques. How should an ammeter be operated to get accurate readings, and why?

Ans. It should be cut out of circuit except while taking a reading, because of the error introduced by the heating effect of the current.

In an ammeter having a capacity of 50 amperes, the error thus introduced will be less than 1 per cent. if connected continuously in circuit with a current not exceeding three-quarters this capacity.

An ammeter of 100 amperes capacity may be used indefinitely in circuit with less than 1 per cent. error up to one-half its capacity, and

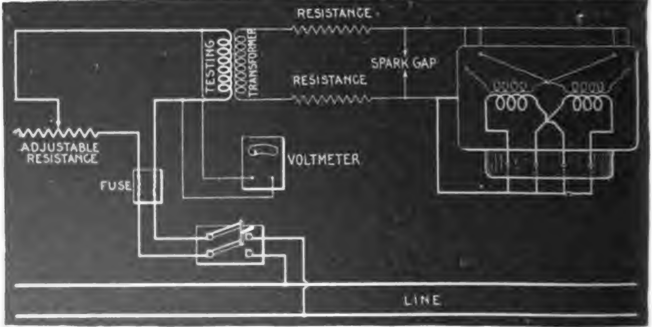


FIG. 2,902.—Transformer insulation test. In applying a 10,000 volt insulation test between the primary and secondary of a transformer, the testing leads should be disconnected from the transformer under test, and a spark gap introduced as shown, with the test needle set at a proper sparking distance for 10,000 volts. A high resistance should be connected in the secondary before closing its circuit, and the voltage gradually increased by cutting out this secondary resistance until a spark jumps across the spark gap. When the spark jumps across the spark gap, the voltmeter reading should be recorded and the testing transformer disconnected. The spark gap should then be increased about 10 per cent. and the high tension leads connected to the transformer under test as indicated in the diagram. In order to equalize the insulation strains, all primary leads should be connected together, all secondary leads not only connected together, but to the core as well. All resistance in the rheostat in the low tension circuit should then be inserted and the switch closed. Gradually cut out secondary resistance until the voltmeter shows the same voltage as was recorded previously when the spark jumped across the gap, and apply this voltage to the transformer for one minute. Insulation tests for a period of over one minute are very unadvisable, as transformers with excellent insulation may be seriously damaged by prolonged insulation tests. The longer the strain to which any insulation is subjected, the shorter the subsequent life of the insulation. Also the greater the applied voltage above the actual operating voltage of the apparatus, the shorter the subsequent life of the insulation. In testing small transformers, the spark gap may be omitted and the voltage of the low pressure coil of the testing transformer measured. This multiplied by the ratio of transformation gives the testing voltage.

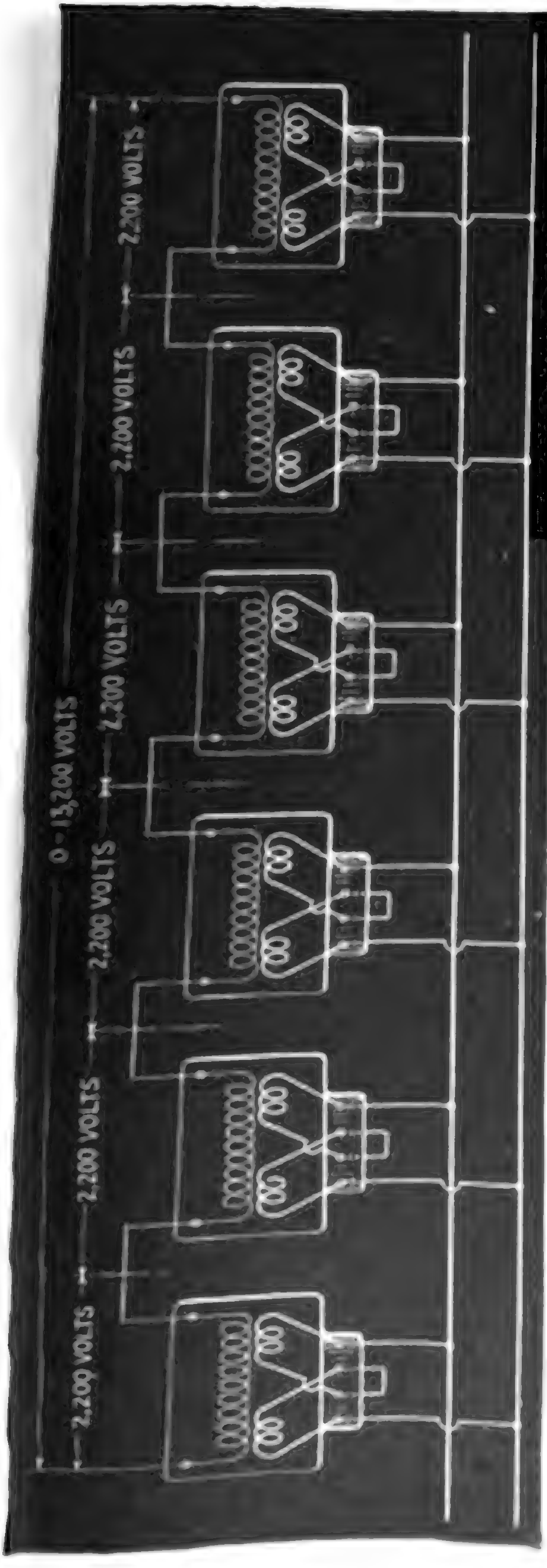


FIG. 2,903.—Transformer insulation test as made when a special high tension transformer be not available. **In this method a** number of standard transformers, connected as shown may be employed, but great care should be taken to have such transformer cases thoroughly insulated from the ground and from one another, in order to minimize the insulation strains in the testing transformers. Care should be taken to insert in the circuit of each testing transformer a fuse, not in excess of the transformer capacity, which will blow, in case of a break down in the apparatus under test. In testing insulation between secondary and core, disconnect the primary entirely, apply one terminal of the testing transformer to the secondary terminals of the transformer under test, and the other terminal of the testing transformer to the core of the transformer under test. This test should also not be in excess of one minute.

for five minutes at three-quarters capacity without exceeding the 1 per cent. limit.

The 150 scale ammeter may be left in circuit for an indefinite length of time at one-third its full capacity, and for three minutes at one-half its full capacity, with a negligible error.

Ammeters of 200 and of 300 ampere capacities must not continuously carry more than one-quarter of these loads respectively if the readings are to have an accuracy within 1 per cent. nor more than one-half these respective number of amperes for three minutes if the same degree of accuracy be desired.

In order to cut or shunt the ammeter out of circuit when not in use, it is customary when wiring the instrument in place, to introduce a switch as a shunt across it; this switch is kept closed except when a measurement is being taken.

When currents larger than 300 amperes have to be measured, ammeter shunts are generally employed, although ammeters up to 500 amperes capacity are manufactured.

Ques. What is used in place of instrument shunts for high pressure alternating current measurements?

Ans. Instrument transformers.

Ques. What important attention should be periodically given to measuring instruments?

Ans. They should be frequently tested by comparison with standards that are known to be correct.

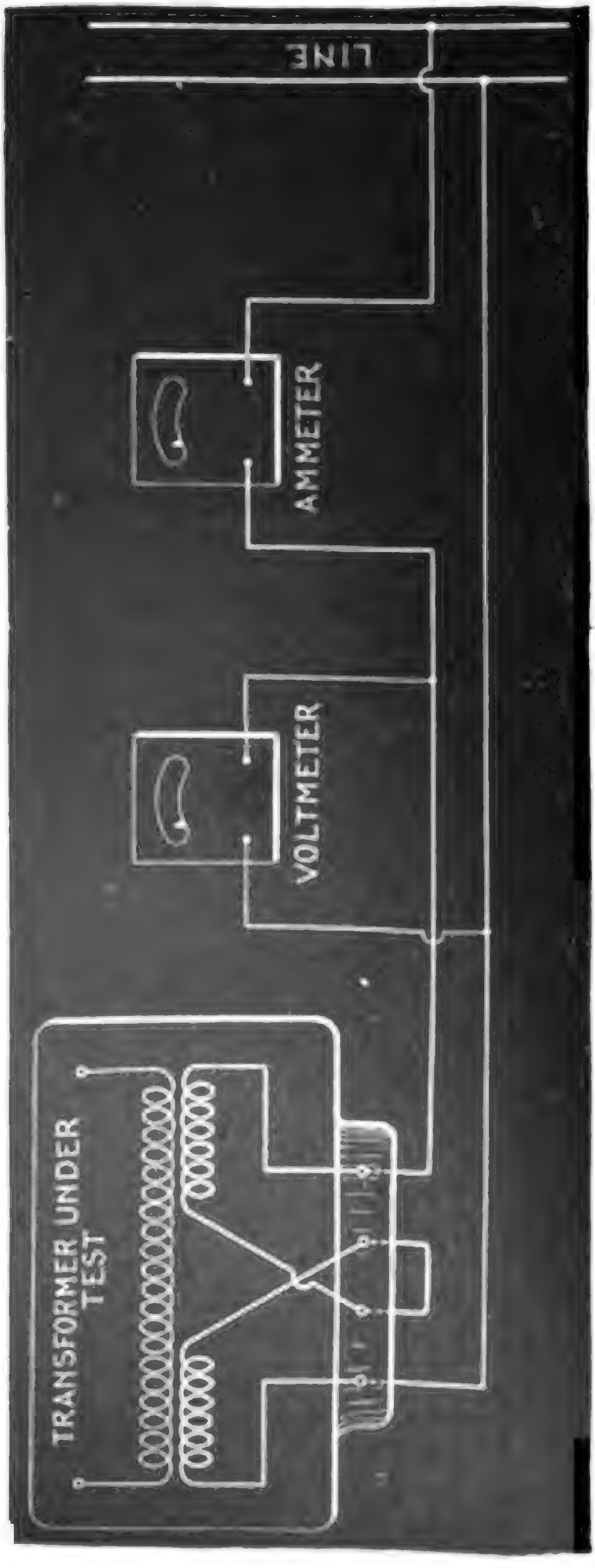


Fig. 2,904.—Transformer internal insulation test, **sometimes called double normal voltage test, from the fact that most transformers** are tested with double normal voltage across their terminals. If either the primary or secondary of the transformer be connected to some source of current with voltage double that of the voltage of the transformer under test, the insulation between adjacent turns, and also the insulation between adjacent layers will be subjected to twice the normal operating voltage. It is good practice to employ high frequency for this test in order to prevent an abnormal current from passing through the transformer. Sixty cycle transformers are usually tested on 133 cycle, and 25 cycle transformers on 60 cycle circuits for this double normal voltage test. It is necessary to insert the resistance in the circuit of the transformer and bring the voltage up gradually, the same as applying other high insulation tests in order to prevent abnormal rises in pressure at the instant of closing the circuit.

Electrical measuring instruments, owing to the nature of their construction and the conditions under which they must necessarily be used, are subject to variations in accuracy. This feature is an annoying one on account of the difficulty of detecting it; a meter may, as far as appearances go, be in excellent working order and yet give readings which are not to be relied upon.

Ridiculous as it may appear, the average station attendant may frequently be seen straining his eyes to read to tenths of a division on the scale of a meter which, if subjected to test, would show an inaccuracy of over 2 per cent.

In testing a meter, by comparing it with a standard, in order to obtain the best results there should be one man at each meter so that simultaneous readings may be taken on both instruments, and the man at the standard meter should maintain the voltage constant while a reading is being taken, by means of a rheostat in the field circuit of the generator supplying the current.

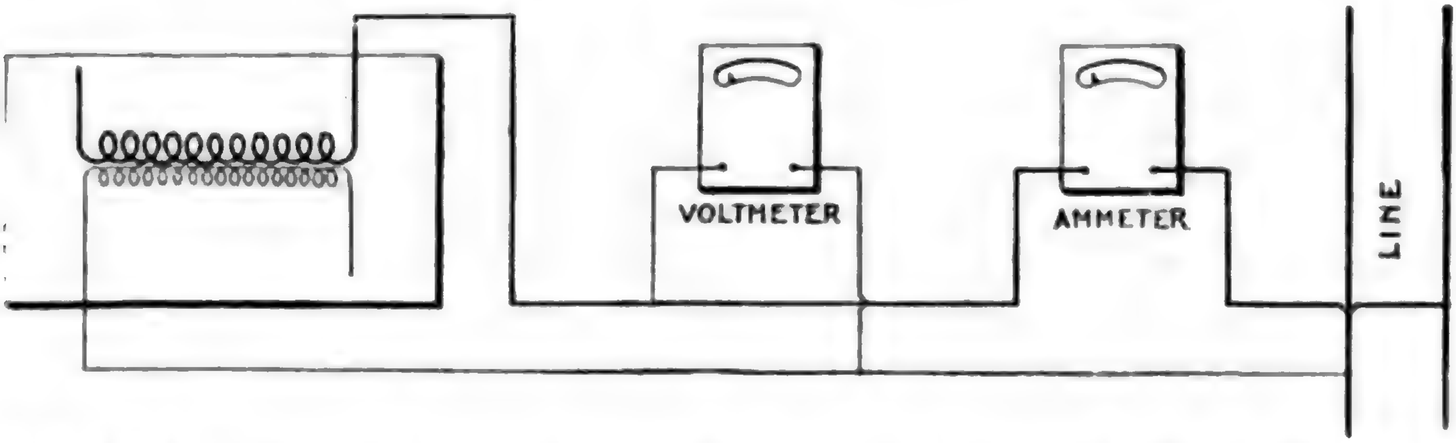


FIG. 2,905.—Transformer insulation resistance test. The insulation, besides being able to resist puncture, due to increased voltage, must also have sufficient resistance to prevent any appreciable amount of current flowing between primary and secondary coils. It is, therefore, sometimes important that the insulation resistance between primary and secondary be measured. This can be done, as here shown. Great care should be taken to have all wires thoroughly insulated from the ground, and to have an ammeter placed as near as possible to the terminals of the transformer under test, in order that current leaking from one side of the line to the other, external to the transformer, may not be measured. Great care is required in making this measurement, in order to obtain consistent results.

Each meter should be checked or calibrated at five or six approximately equidistant points over its scale; the adjustable resistance being varied each time to give a deflection on the standard meter of an even number of divisions and the deflection on the other meter recorded at whatever it may be. Having obtained the necessary readings, the calculation of the constant or multiplying factor of the meter undergoing test is next in order.

This may best be shown by taking an actual case in which a 150 scale voltmeter is being tested to determine its accuracy. The data and calculations are as follows:

Readings on standard meter	Readings on meter tested	Constant
150	149.2	150 ÷ 149.2 = 1.005
125	125.0	125 ÷ 125.0 = 1.000
100	98.9	100 ÷ 98.9 = 1.011
75	73.6	75 ÷ 73.6 = 1.019
50	50.0	50 ÷ 50.0 = 1.000
25	24.8	25 ÷ 24.8 = 1.008
		6.043

Average constant for six readings, 6.043 ÷ 6 – 1.007.

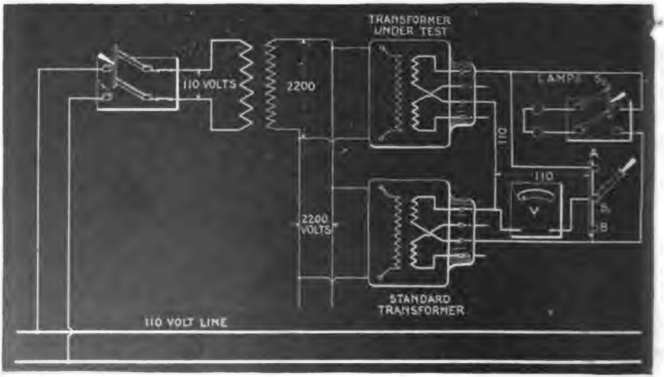


FIG. 2,906.—Transformer winding or ratio test. The object of this test is to check the ratio between the primary and the secondary windings. For this purpose a transformer of known ratio is used as a standard. Connect the transformer under test with a standard transformer as shown. Leave switch S_2 open. With the single pole double throw switch in position S_1B, the voltmeter is thrown across the terminals of the standard transformer. With the switch in position S_1A, the voltmeter is thrown across the terminals of the transformer under test. The voltmeter should be read with the switch in each position. If the winding ratio be the same as that of the standard transformer, the two voltmeter readings will be identical.

It may be stated in general that before taking the readings for this test, the zero position of the pointer on the meter tested should be noted, and if it be more than two-tenths of a division off the zero mark, the case of the meter should be removed and the pointer straightened.

Furthermore, it will be noticed from the readings here recorded that the test is started at the high reading end of the scale; this is done in order that the pointer may gradually be brought up to this spot, by slowly cutting out of circuit the adjustable resistance, and thus show whether or not the pointer has a tendency to stick at any part of the scale. If the meter seem to be defective in this respect, it should be remedied either by bending the pointer or scale, or by renewing one or both of the jewels, before the comparison with the standard is commenced.

It is obvious from the readings recorded for the 150 scale voltmeter, that as compared with the corresponding deflections of the standard, the former are a trifle low.

In order to determine for each observation how much too low they are, it is necessary to divide each reading on the standard by the corresponding reading on the meter tested. The result is the amount by which a deflection of this size on the meter tested must be multiplied in order to obtain the exact reading. This multiplier is called a constant, and as shown, a constant is determined for each of the six observations.

The average constant for the six readings is then found, and this is taken as the constant for the meter as a whole; that is, whenever this 150 scale voltmeter is used, each reading taken thereon must be multiplied by 1.007 in order to correct for its inaccuracy.

The most convenient and systematic way of registering the constant of a meter is to write it, together with the number of the meter and the date of its calibration, in ink on a cardboard tag and loop the same by means of a string to the handle or some other convenient part of the meter.

NOTE.—**Transformer polarity test.** A test of importance in the manufacture of transformers, and sometimes necessary for the user, is the so called *banking* or *polarity* test. The transformers from any particular manufacturer have the leads brought out in such a manner that a transformer of any size can be connected to primary and secondary lines in a given order without danger of blowing the fuses due to incorrect connections. All manufacturers of transformers, however, do not bank transformers in the same way, so that it is necessary in placing transformers of different makes to test for polarity. This is done as shown n fig. 2,906. One transformer is selected as a standard and the leads of the second transormer connected as indicated in the diagram. If the transformers be 1,100–2,200 volts to 110-220, two 110 volt lamps are connected in the secondaries of the transformers as indicated, while the primary of the transformer is connected across the line. In transformers built for two primary and two secondary voltages, it is necessary to test each primary and each secondary. The diagram shows the method of connecting one 2,200 volt coil and one 110 volt coil to the transformer to be tested. When the primary circuit of the transformer under test is closed, and if the secondary leads of the 110 volt coil under test be brought out of the case properly, the two 110 volt lamps should be brightly illuminated. If, on the other hand, the two 110 volt terminals have been reversed, no current will flow through the lamps. If these two terminals be found to be brought out correctly, transfer the secondary leads of the transformer under test to the second 110 volt coil. Upon closing the primary circuit, the lamp should again be brightly illuminated. Repeat this process with each of the secondary coils and the other primary coil, and if the lamps show up brightly in every case on closing the primary circuit, all leads have been properly brought out. If on any tests the lamps do not light up brightly, the leads on the transformer must be so changed as to produce the proper ban-

Ques. What are the usual remedies applied to a voltmeter to correct a 3 or 4 per cent. error?

Ans. They consist of straightening the pointer, varying the tension of the spiral springs, renewing the jewels in the bearings, altering the value of the high resistance, and, in the case of a direct current instrument, strengthening the permanent magnet.

Ques. How is the permanent magnet strengthened?

Ans. After detaching it from the instrument, wrap around several turns of insulated wire, and pass through this wire for a short time 3 or 4 amperes of direct current in such a direction as to reinforce the magnet magnetism.

Ques. How may the value of the high resistance of a voltmeter be altered?

Ans. Determine the resistance of the voltmeter and add or subtract, according as the reading is high or low, a certain length of wire whose resistance is in per cent. of the voltmeter resistance the same as the per cent. of error.

NOTE.—The complete calibration of a two scale voltmeter does not, as might be supposed, necessitate that the readings on both scales be checked with standards, for since the resistance corresponding to the one scale is always some multiple of the resistance of the other, the constants of the two scales are proportional. For instance, if S = the reading at the end of the high scale of the voltmeter; S^1 = the reading at the end of the low scale of the voltmeter; R = the resistance in the meter corresponding to the high scale; R = the resistance in the meter corresponding to the low scale; K = the constant for the high scale, and K^1 = the constant for the low scale. Then

$$SK \div R = S^1K^1 \div R^1$$

from which

$$K^1 = SKR \div S^1R$$

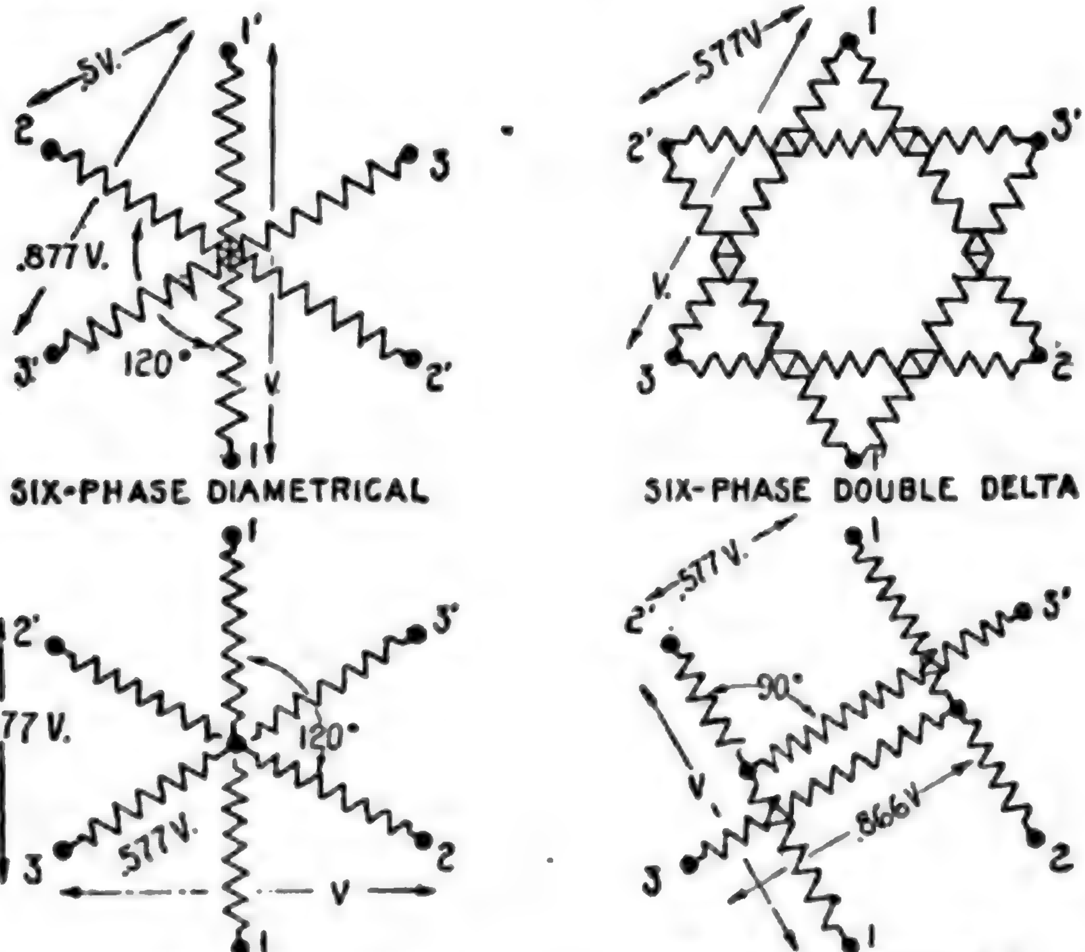
That is to say, if the respective resistances corresponding to the two scales be known, and the constant of the high scale be determined by comparison with a standard, then by aid of these known values and the maximum readings on the two scales, the constant of the low scale may be calculated. It is also possible to calculate the constant of the high scale if the constant of the low scale be known, together with the values of the resistances corresponding to the two scales; for from the equation previously given.

$$K = RS^1K^1 \div R^1S$$

Ques. What is a frequent cause of error in an alternating current meter, and why?

Ans. The deterioration of its insulation, which permits the working parts of the instrument coming in contact with the surrounding metal case.

A convenient method of testing for deterioration of insulation is shown in fig. 2,905.



SIX-PHASE DIAMETRICAL

SIX-PHASE DOUBLE DELTA

SIX-PHASE DOUBLE Y

SIX-PHASE DOUBLE T

FIG. 2,907.—Diagrams showing various synchronous converter transformer connections. The diametrical connection is used most frequently as it requires only one secondary coil on each transformer, this being connected to diametrically opposite points on the armature winding. The middle points can be connected together and a neutral obtained the unbalanced three wire direct current having no distorting effect. With diametrical secondaries, the primaries should preferably be connected delta, except with regulating pole converters where they must be connected Y. Diametrical secondaries with delta primaries should not be used with regulating pole converters. Double star connection of secondaries may, however, be used with delta primaries, and is free from the trouble of the triple harmonic of the transformer appearing in the primary. In this case, however, the two secondary neutrals must not be connected with each other.

How to Test Generators.—In the operation of electrical stations, many problems dealing with the generators installed therein can be readily solved by the aid of characteristic curves,

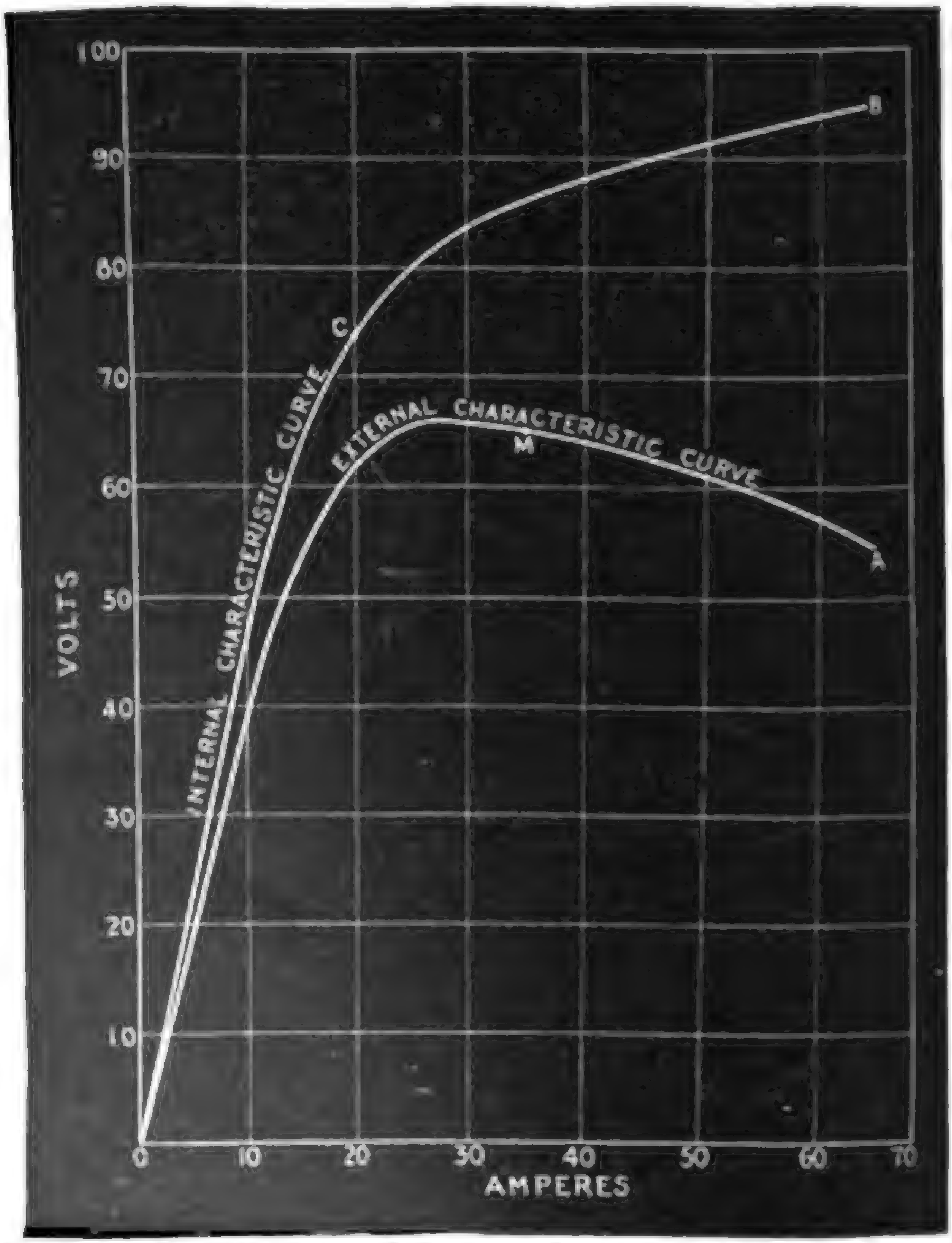


FIG. 2,908.—General form of characteristic curves for a series dynamo. The general curve that may be expected is OA. It is obtained practically in the same manner as for the shunt characteristic curve, except that no field rheostat is employed. Commencing with no load or amperes, there will probably be a small deflection noticeable on the voltmeter, due to the residual magnetism. The other readings are taken with successive reductions of main current resistance. The curve OA thus obtained for a certain series generator is practically a straight line at the beginning, representing thereby a proportional increase of voltage with increase of current, but after a certain current is reached (about 20 amperes in this case) the curve flattens and takes a downward direction. The turning point occurs in the characteristic curves of all series generators, and it denotes the stage at which the iron magnet cores become so saturated with lines of magnetic force that they will not readily allow more to pass through them; this turning point is technically known as the point of saturation, and the current corresponding (20 amperes in this case) is called the critical current of the dynamo. The point of saturation in any given series machine is governed by the amount of iron in the magnetic circuit; its position in the curve therefore varies according to the design of the generator as does also the critical current. The value of the latter is important inasmuch as the valuable features of a series generator assert them-which bear a relation to the generators similarly as do indicator diagrams to steam engines.

In steam engineering, a man who did not fully understand the method of taking an indicator diagram would be considered not in touch with his profession, and in electrical engineering the same would be true of one ignorant of the method of obtaining characteristic curves.

The necessary arrangement or connection of the generator from which it is desired to obtain a characteristic curve, consists in providing a constant motive power so that the machine may be run at a uniform speed, and when the field magnets of the generator are separately excited the field current from the outside source must also be maintained constant, preferably by a rheostat connected in the field of the auxiliary exciting machine. It is also necessary in every case that means be provided for varying the main current of the generator step by step from zero to maximum. This may best be done by employing a water rheostat, as shown in fig. 2,909.

Ques. What instruments are needed in making a test of dynamo characteristics?

Ans. A voltmeter, ammeter, speed indicator, the usual switches and rheostats.

Ques. How is the apparatus connected?

Ans. It is connected as shown in fig. 2,910.

Ques. Describe the test.

Ans. Having completed the preliminaries as in fig. 2,910, the test should be started with the main circuit of the generator

FIG. 2,908.—*Text continued.*

selves only when the machine is supplying a greater number of amperes than that of the critical current, for if the series generator be worked along that part M A of the curve to the right of the point of saturation it becomes nearly self-regulating as regards current, because as the current increases the voltage drops. In the diagram in addition to the characteristic curve O A, which may more definitely be called an external characteristic curve on account of representing the conditions external to the generator, there is shown a total characteristic curve, O C B. The latter curve represents the relation between the current and the total voltage developed in the armature, and may be plotted from the external characteristic curve if the resistance of the armature between brushes and the resistance of the series field winding be known. For example, assume these combined resistances amount to .6 ohm. At 30 amperes there would be required 30×.6=18 volts to force this current through the armature and field windings. At 30 amperes the external pressure is 65 volts, as shown by the curve O A; the total voltage developed for 30 amperes is, therefore, the external voltage plus the internal voltage or 65+18=83 volts. Plotting 83 volts for 30 amperes will give one point for the external characteristic curve of this machine, and by determining in like manner the total voltages developed for six or eight different currents over the scale, sufficient data will be at hand for plotting and drawing in the curve O C B.

open. Then, in the case of the shunt machine, the speed should be made normal and the field rheostat adjusted until the voltmeter reading indicates the rated voltage of the machine at no load and readings taken. The electrodes of the water rheostat should be adjusted for maximum resistance and main circuit closed, and a second set of readings taken. Several sets of readings are taken, with successive reductions of water rheostat resistance. The results are then plotted on coordinate paper giving the characteristic curve shown in fig. 2,908.

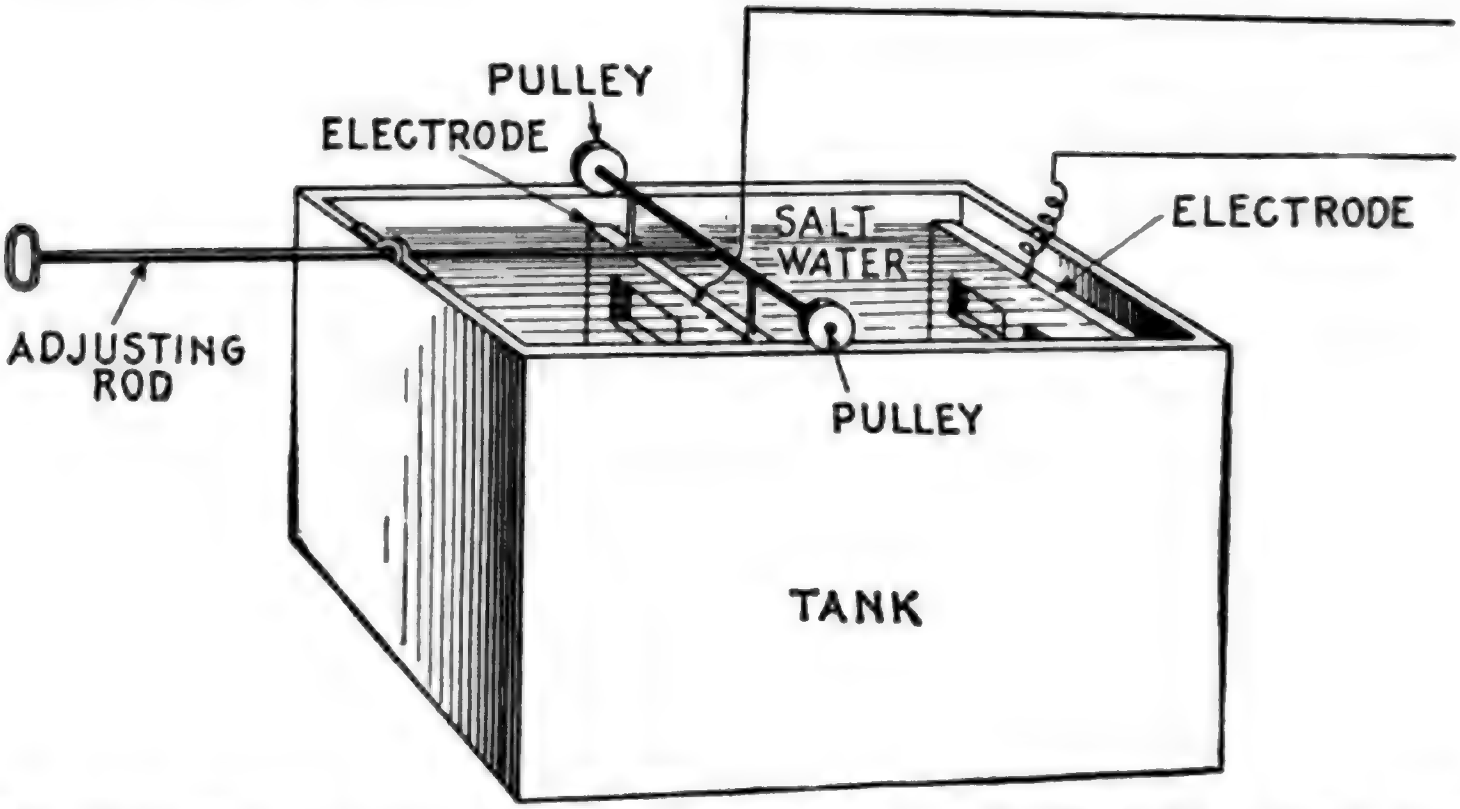


FIG. 2,909.—Water rheostat. It consists essentially of a tank of suitable size containing salt water into which are placed two electrodes having means of adjustment of the distance separating them. The solution depends on the voltage. Pure water is seldom used for pressures under 1,000 volts. The size of the tank is determined by the size of the electrodes, and roughly the size of the latter equal the number of amperes. With a current density of one ampere per square inch, a water solution gives a drop of 2,500 to 3,000 volts per inch distance between the plates. Where high voltage is used, the water must be circulated through and from the tank by rubber hose allowing for 2,500 volts, a length of 15 to 20 feet of 1 inch hose to prevent grounding. In place of the arrangement shown above, a barrel may be used for the tank, and for the electrodes, coils of galvanized iron wire. This is the simplest form and is satisfactory.

Ques. What does the characteristic curve (fig. 2,911) show?

Ans. An examination of the curve shows that the highest point of the curve occurs at no load or 0 amperes; that as the current is increased, the voltage drops, first slightly to the point B and then rapidly until the point E is reached, when any further lowering of resistance in the main circuit to increase the current causes not only a rapid decline in the voltage but also of the current until both voltage and current become approximately zero.

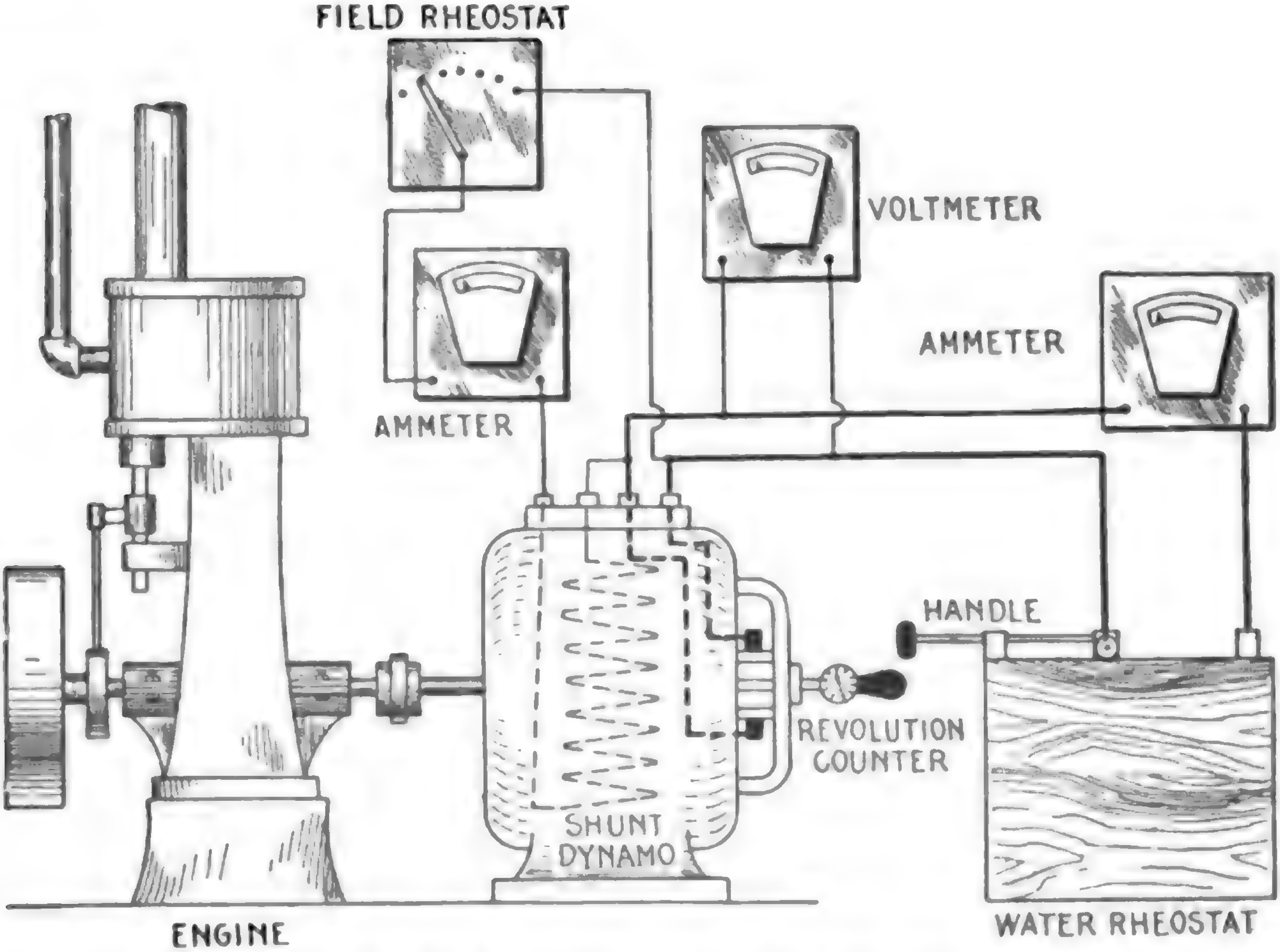


FIG. 2,910.—Connections for test of dynamo. During the test, one man should be assigned to the tachometer, another man to the water rheostat, and there should preferably be one man at each of the electrical measuring instruments. In order to enable the man at the tachometer to keep the speed constant, he should be in communication either directly or indirectly with the source of the driving power, and the man at the water rheostat should be in plain view of the man reading the ammeter so that the latter party may signal him for the proper adjustment of the rheostat in order that the desired increase of current be obtained for each set of readings.

In some generators, a very slight current results even when the terminals of the machine are actually short circuited; that is, due to residual magnetism in the pole pieces, the lower portion of the curve often terminates, not exactly at zero, but at a point some distance along the current line.

The working portion of the curve is from A to C, at which time the machine is supplying a fairly constant voltage. From C to E shows a critical condition of affairs, while the straight portion D O represents the unstable part of the curve caused by the field current being below its proper value.

The position of the point C determines the maximum power the machine is capable of developing, being in this case $(47.5 \times 25) \div 746 =$ 1.59 horse power.

Ques. How may the commercial efficiency of a generator be determined?

Ans. To obtain the commercial efficiency, the *input* and *output* must be found for different loads.

The input may be found by running the generator as a motor at its rated speed, loading it by means of a Prony brake. The generator must be stripped of all belting or other mechanical connections, supplied with its normal voltage and full load current, and the pressure of the Prony brake upon its armature shaft or pulley adjusted until the rated speed of the armature is obtained. The data thus obtained is substituted in the formula

$$\text{input in brake horse power} = \frac{2\pi \text{ L W R}}{33{,}000} \quad . \quad . \quad . \quad . \quad (1)$$

in which

L = length of Prony brake lever;
W = pounds pull at end of lever;
R = revolutions per minute.

The output or electrical horse power for the same load is easily calculated from the formula

$$\text{output in electrical horse power} = \frac{\text{amperes} \times \text{volts}}{746} \quad . \quad . \quad (2)$$

After obtaining value for (1) and (2) the commercial efficiency for the load taken is obtained from the formula

$$\text{commercial efficiency} = \frac{\text{output}}{\text{input}} \quad . \quad . \quad . \quad . \quad (3)$$

Having obtained the commercial efficiency, the difference between the ideal 100 per cent. and the efficiency found will be due to certain losses in the generator. These losses may be classified as

1. Mechanical;
2. Electrical.

The mechanical losses are the friction of the bearings and brushes, and air friction. The electrical losses consist of the eddy current loss, hysteresis loss, armature resistance loss, and field resistance loss.

In testing for these losses, the generator to be tested should be belted to a calibrated motor which latter machine should preferably be of the constant pressure, shunt wound type.

The friction of the bearings and belt of the generator are determined together by raising the brushes off its commutator and running it at the rated speed by means of the calibrated motor.

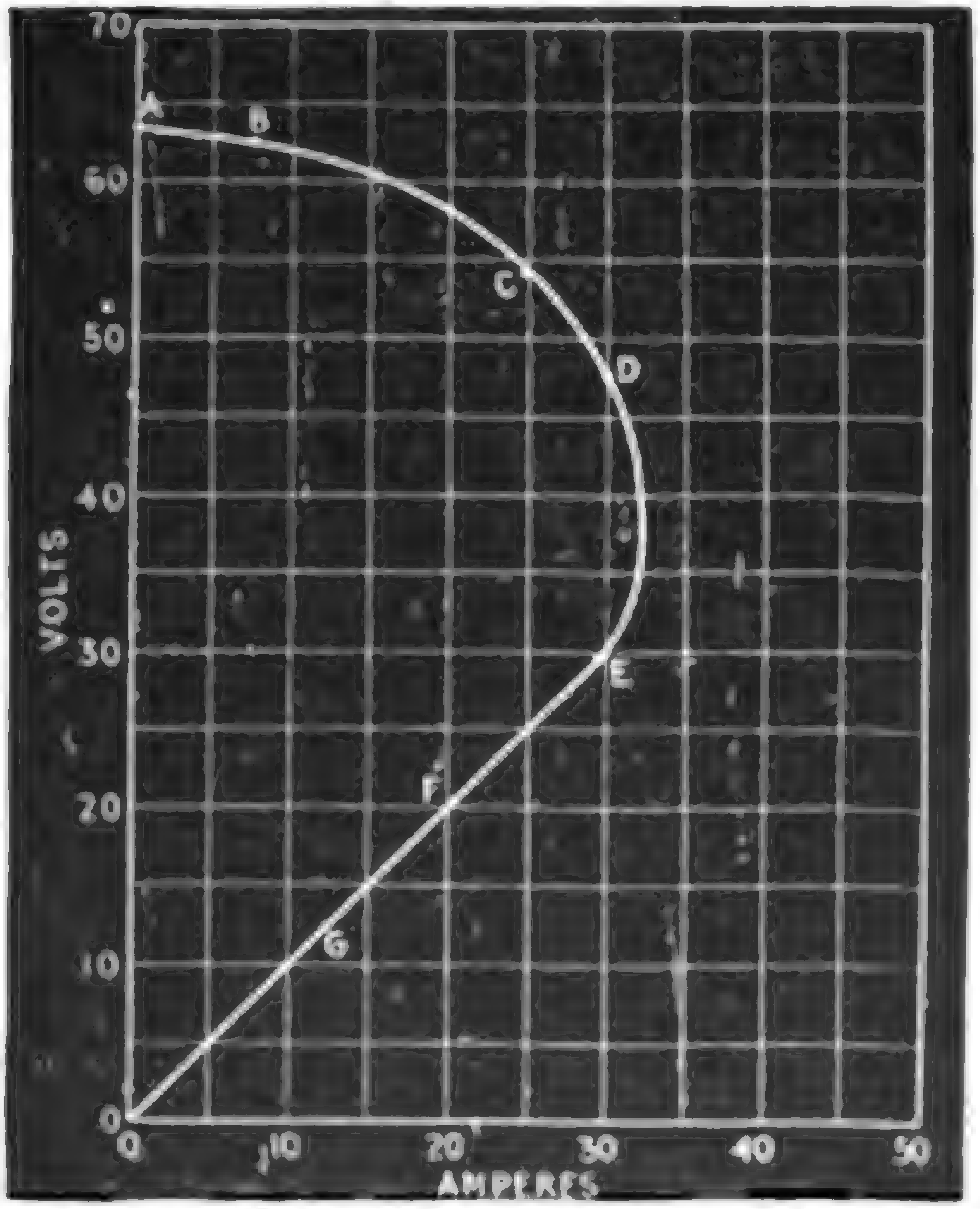


FIG. 2,911.—Characteristic curve of shunt dynamo. Suppose in making the test, the deflections on the meters for the first readings be 63 volts and 0 amperes, the plotting of these values will give the first point on the curve. Similarly, the second readings with main circuit closed and maximum resistance in the water rheostat may be assumed to be 62.5 volts and 7.5 amperes, which plotted gives the second point B. A still further lowering of the plate will permit a stronger current in the main circuit, and the value of this together with its corresponding voltage will give a third point for the curve. Neither for this reading, however, nor for the following readings of the test should the field rheostat be altered. When six or eight points ranging from zero to a maximum current have been obtained and plotted, a curved line should be drawn through them such as shown through ABCDEFG0, the *characteristic curve* of the dynamo. While the curve may be sketched in free hand, it should preferably be drawn by the aid of French curves. In case the French curve cannot be exactly made to coincide with all the points as for instance C and D, it should be run in between giving an average result, and smoothing out irregularities, or small errors due to the "personal equation." The meter of course must be correct or calibrated and the readings corrected by the calibration coefficient.

The amount of power as ascertained from the calibration curve of the motor for the voltage and current used therein when driving the generator as just explained, is a measure of these two losses. The power thus used is practically constant at all loads and is about 2 per cent. of that necessary to drive the generator at full load.

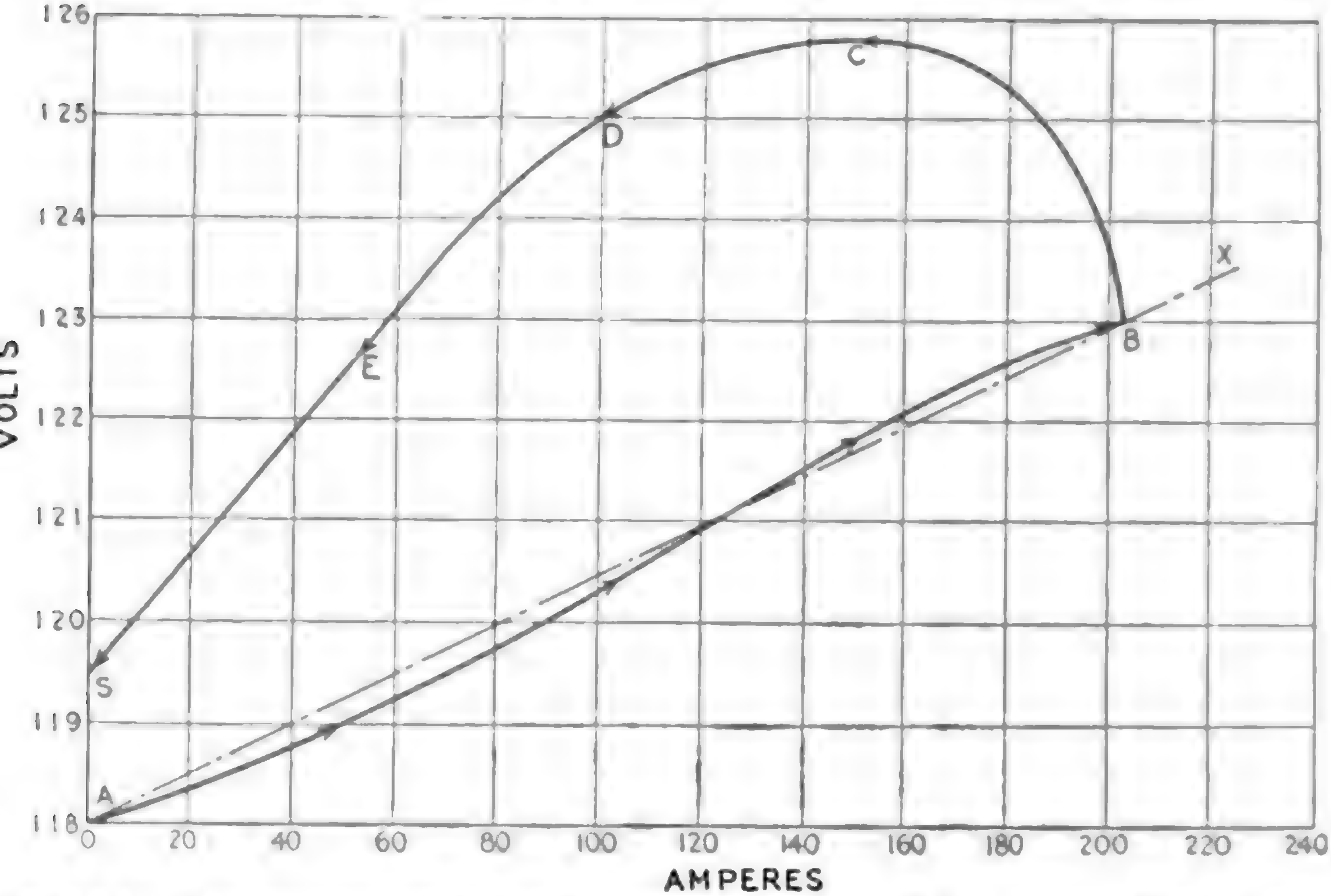


FIG. 2,912.—Characteristic curves for a compound dynamo. If the machine be over compounded, the characteristic curve has the form of the curve A B, which curve was obtained from a machine overcompounded from 118 to 123 volts, and designed to give 203 amperes at full load. The preliminary arrangements for testing a compound dynamo are similar to those for a shunt generator, and if the shunt across the series field winding be already made up and in position, the readings are taken precisely in the same manner. It is generally considered sufficient if observations be recorded at zero, ¼, ½, ¾ and full load. If it be desired to ascertain the effect which residual magnetism has upon the field magnets the current is decreased after the full load point is reached without opening the circuit, and readings are taken in succession at ¾, ½, ¼ and zero load giving in this case the curve B C D E S. It is thus seen that residual magnetism exerts no small effect upon the voltage obtained at the different loads, for had there been no residual magnetism in the field magnets the curve B C D E S would have coincided with the curve A B. The curve A B, and the straight line A X drawn through the points A and B, are almost identical, and as A X represents the theoretical characteristic curve for the machine, it is seen that compounding is practically perfect. In order to insure such accurate results being obtained, providing the machinery be correctly designed, requires considerable care in taking the readings; for example, each step or load on the ascending curve should not be exceeded before the corresponding deflection is taken, else the residual magnetism will cause the pressure reading to be higher than it actually should be, and the following pressure readings will also be affected in the same manner. In case the shunt to be employed across the series field has not been made up, it is advisable to perform a trial test before taking the readings for the curve as previously described. The trial test consists in taking two readings, —one at no load and the other at full load, the shunt being so adjusted as to length and section that the desired amount of compounding will be obtained in the latter reading with normal voltage at no load. If the first trial fail to produce the desired result by giving too low a voltage at full load, the length of the shunt across the series field should be increased, or its section should be reduced by employing a less number of strips in its makeup; again, if the voltage at full load be higher than that desired, there must be made a decrease in length or an increase of section in the shunt employed.

The friction of the brushes can very conveniently be determined next by lowering them on the commutator and giving them the proper tension.

The increase in power resulting from the greater current that will now be taken by the motor to run the dynamo at its rated speed, will be a measure of this loss. In general, its value will be about .5 per cent. of the total power required to drive the dynamo at full load, and this also will remain constant at all loads.

The friction of the air upon the moving armature of the dynamo cannot be determined experimentally, but theoretically this loss is small and may be estimated as .5 per cent.; it is also constant at all loads.

The core loss may be determined experimentally by exciting the field magnets of the dynamo with the normal full load field current through the magnet coils, and noting the increase of power required by the motor to maintain the rated speed of the dynamo thus excited under no load, over that necessary under the same conditions with no field excitation. This increase of power will be the value of the core loss. The core loss is approximately 3 per cent. of the power required to operate the dynamo at full load, and it is constant at varying loads. If it be desired to divide the core loss into its component parts, it is necessary also to run the dynamo under the same conditions as before with field excitation but at half its rated speed. If, then,

H = the power lost in hysteresis at rated speed,
E = the power lost in eddy currents at rated speed,
T = the power lost in hysteresis and eddy currents at rated speed,
S = the power lost in hysteresis and eddy currents at half speed,

there may be formed the two following equations:

$$T = H + E, \text{ and } S = \frac{H}{2} + \frac{E}{2},$$

from which the elimination of H will give $E = 2T - 4S$.

The value of the eddy current loss thus found will be about 1½ per cent., and constant at all loads.

Having previously ascertained the power lost in both eddy currents and hysteresis, and knowing now the power lost in eddy currents alone, it is easy to find that lost in hysteresis by simply subtracting the latter known value from the former. The value of the hysteresis loss is therefore approximately 1½ per cent., and it is constant at different loads.

There yet remains to be determined the armature resistance loss and the field resistance loss. As for the calibrated motor, this may be disconnected from the dynamo, as it need not be used further in the test.

The armature resistance is the resistance of the armature winding of the dynamo, between the commutator bars upon which press the positive and negative brushes. Assume that the value of the armature resistance be known, call this value R ohms, together with that of the full load armature current, which is also known and which call I amperes, this is sufficient data for calculating the armature resistance loss at full load. It is evident that to force the full load current I through the armature resistance R will require a pressure of R volts, and that the watts lost in doing so will be the voltage multiplied by the current. The armature resistance is consequently

$$IR \times I = I^2R \text{ watts}$$

or, expressed in horse power it is

$$I^2R \div 746$$

At full load it is usually about 2 per cent. of the total power required to drive the generator fully loaded. The armature resistance loss varies in proportion to the load, in fact, as the last expression shows, it increases as the square of the armature current.

The field resistance loss is calculated in the same manner as just explained for the armature resistance loss, it being equal in horse power to the square of the full load field current multiplied by the resistance of the field winding and divided by 746. In a shunt dynamo it is practically constant at 2 per cent. of the total power at full load, but in a series or in a compound generator it will vary in proportion to the load.

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